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Gaze-Contingent Display Changes as New Window on Analytical and Holistic Face Perception in Children With Autism Spectrum Disorder

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The strength of holistic face perception in children with autism spectrum disorder (ASD) was evaluated by applying the gaze-contingent mask and window technique to a face matching and discrimination task in 6- to 14-year-old children with (n = 36) and without ASD (n = 47), and by examining fixation patterns. Behavioral results suggested a slower and less efficient face processing in the ASD sample compared with the matched control group. Comparing the moving mask and window conditions revealed a reduced holistic face processing bias in the younger age group but not in the older sample. Preferential viewing patterns revealed both similarities and differences between both participant groups.

The human brain is able to discriminate and recognize facial stimuli in a fascinatingly fast and effortless manner, despite their very high intraclass similarity (Bruce & Young, 2012). Efficient face processing is based on a highly specialized network of brain regions (e.g., Haxby, Hoffman, & Gobbini, 2000; Kanwisher, 2006), including a specific part of the fusiform gyrus—the so-called fusiform face area (Kanwisher, McDermott, & Chun, 1997; for a meta-analysis and review discussing atypical FFA functioning in autism spectrum disorder [ASD], see Di Martino, Uddin, Sklar, Castellanos, & Milham, 2009; Golarai, Grill-Spector, & Reiss, 2006).

Faces are considered quintessential *gestalts* because the perception of individual features is strongly dependent on the whole face. Typical face processing is characterized by an interplay between holistic and analytical processing, and more so than for other objects, face processing relies strongly on holistic processing. There is substantial debate about the specific definition of holistic processing and its underlying mechanisms (Behrmann, Richler, Avidan, & Kimchi, 2015; Maurer, Grand, & Mondloch, 2002; Piepers & Robbins, 2012; Rossion, 2013). Holistic processing implies a specialized form of stimulus processing, which is crucial for the high speed and efficiency of typical face perception, involving the interactivity and integration of featural and relational information in a face. Consistent with Rossion (2008, 2009, 2013), we define holistic processing as “the simultaneous integration of the multiple parts of a face into a single perceptual representation.” This definition does not imply face templates without representation of individual face

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features, such as color, individual face parts, or the spacing between them (so-called "configural information"). In this sense, holistic face processing entails the simultaneous processing and representation of different types of information in interaction with each other instead of in isolation. Holistic processing is often contrasted with analytical face processing (Bruce & Young, 2012), which is characterized by a piecemeal, part-by-part sampling of detailed information about the parts.

The clinical prominence of social impairments in ASD encouraged a wealth of studies investigating the face processing (for reviews, see Dawson, Webb, & McPartland, 2005; Jemel, Mottron, & Dawson, 2006; Sasson, 2006). Individuals with ASD show diminished face recognition and face memory skills (for recent reviews, see Tang et al., 2015; Weigelt, Koldewyn, & Kanwisher, 2012). In addition, the (atypical) quality of face perception is also a prominent research topic: *How* do individuals with ASD process faces? Two core aspects of atypical face perception in ASD have been studied.

A first line of work evaluated the preferential viewing patterns of individuals with ASD, and revealed an overall reduced saliency of faces (for reviews, see Ames & Fletcher-Watson, 2010; Falck-Ytter & von Hofsten, 2011), even in very young children with ASD (for a review, see Falck-Ytter, Bölte, & Gredebäck, 2013). Furthermore, individuals with ASD seem to fixate on core face features to a lesser extent than comparison groups. However, the literature on social attention in ASD is characterized by inconsistent results. Meta-analyses concluded that the ASD group shows a decreased number of fixations on the eyes region but no atypical attention to the mouth area (Papagiannopoulou, Chitty, Hermens, Hickie, & Lagopoulos, 2014).

A second line of studies evaluated the strength of holistic face processing in individuals with ASD. An atypical perceptual style, more locally oriented and less inclined toward global processing, is central to neurocognitive theories of ASD such as the weak central coherence theory (Frith & Happé, 1994; Happé & Booth, 2008; Happé & Frith, 2006) and the enhanced perceptual functioning hypothesis (Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert, & Burack, 2006). Note that these theories only make explicit claims about nonsocial perception (but see Frith, 1989; Frith & Happé, 1994, for the link between central coherence and social insight). One could argue, however, that perceptual organization involved in the perception of nonsocial objects also plays a crucial role in face perception (for empirical evidence in ASD, see Behrmann et al., 2006). Neurocognitive theories of perception in ASD have inspired an extensive number of studies on holistic face perception in this clinical population, mostly involving manipulations of behavioral characteristics that are generally accepted markers of holistic face processing, demonstrating, for instance, the composite face effect (Rossion, 2013; Young, Hellawell, & Hay, 1987), the face inversion effect (Yin, 1969), the Thatcher illusion (Thompson, 1980), or the part–whole effect (Tanaka & Farah, 1993).

Early work on holistic face perception in individuals with ASD revealed, for instance, reduced face inversion effects (e.g., Hobson, Ouston, & Lee, 1988) or attenuated composite face illusions (Teunisse & de Gelder, 2003), which has been taken to suggest a more locally and less globally oriented face processing strategy. However, later studies have failed to replicate these previous results, leaving the issue of holistic face perception in ASD open to debate. An extensive review article on this topic (Weigelt et al., 2012) concluded that there was no strong evidence for a reduced global or enhanced local face processing style in ASD. An update, however, did suggest an attenuated global face processing style in ASD, based on studies using subtle manipulations and evaluating adults with ASD (Tang et al., 2015). For example, decreased face recognition performances were found in individuals with ASD when relying on low spatial frequencies (assumed to contain coarse-scale, global information) compared with high spatial frequencies (Deruelle, Rondan, Salle-Collemiche, Bastard-Rosset, & Da Fonseca, 2008). Unfortunately, all of these studies provided rather *indirect* support for holistic processing: They demonstrated that the perceptual representations of facial features are influenced by other features or by their overall configuration, but they are unable to indicate differences in the underlying processes leading to this representation.

Holistic face processing was also assessed more *directly*, in the sense that the underlying process leading to the face representation was manipulated. The gaze-contingent window and mask technique, developed in reading research (McConkie & Rayner, 1975), was adapted to face perception (Van Belle, De Graef, Verfaillie, Busigny, & Rossion, 2010; Van Belle, De Graef, Verfaillie, Rossion, & Lefevre, 2010; Van Belle et al., 2011). Gaze-contingent stimulus presentation implies actively changing the observers' visual input contingent with their actual fixation location with eye-tracker technology. With a gaze-contingent mask and window, Van

Belle and colleagues (Van Belle, De Graef, Verfaillie, et al., 2010; Van Belle, De Graef, Verfaillie, Rossion, et al., 2010; Van Belle et al., 2011) manipulated the amount of simultaneously accessible facial information, and hence, they directly intervened with holistic and analytical processing. In the moving mask condition, a scotoma of roughly the size of one facial feature covers the central part of the visual field, and hence, high-resolution foveal input is blocked. A moving mask only provides access to nonfixated, low-resolution (*blurry*) peripheral information. Given that analytical processing is based on the sequential investigation of detailed information available in the foveal part of the visual field, one expects the mask condition to interfere more with analytical than holistic processing. In the window condition, on the contrary, the visible area of the stimulus is restricted to an area corresponding with one facial feature, centered on the fixated location on the stimulus. In this way, most facial information is covered, while foveal information is still available for detailed processing. Hence, the simultaneous integration of all information is hindered, and consequently, the moving window affects holistic processing more than analytical processing.

Van Belle, De Graef, Verfaillie, Rossion, et al. (2010) showed a clear performance drop for upright faces to the level of inverted faces when vision was restricted with a gaze-contingent window. Those circumstances forced viewers into an analytical processing style, which caused the face inversion effect to disappear. However, the face inversion effect was increased with a gaze-contingent mask, hindering mainly analytical processing. Hereby, they proved that the processing of upright faces relies on the whole face instead of sequential sampling of separate facial features. Likewise, the gaze-contingent mask and window technique has revealed problems with holistic face processing—and not with analytical face processing—in patients with prosopagnosia, a face-specific recognition deficit due to brain damage (Busigny et al., 2014; Van Belle et al., 2011; Van Belle, De Graef, Verfaillie, et al., 2010).

The search for atypical viewing patterns and the evaluation of local–global face processing have both yielded highly influential studies in ASD research. However, these topics have mostly been investigated separately, with their own paradigms and methodologies. The present study combines them in a developmental study with two clinical and control groups. We tested children in two different age groups: in Experiment 1, 6- to 10-year-olds were tested, and in Experiment 2, participants were aged 10- to 14-year-olds. Children show remarkable face processing abilities from very early on in life: Newborns are more sensitive to faces and facial configurations than scrambled faces (e.g., Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991), and they can already distinguish their mother's face from others soon after birth (e.g., Field, Cohen, Garcia, & Greenberg, 1984). Early developmental theories suggested a default analytical face processing mode in children, switching into a holistic face processing style in older children and adults. Later evidence, however, has demonstrated that children show all typical markers of holistic face processing by the age of 6 (Crookes & McKone, 2009; de Heering, Houthuys, & Rossion, 2007; Mondloch, Pathman, Maurer, Le Grand, & de Schonen, 2007; Pellicano & Rhodes, 2003), though quantitative differences can still be noted and face processing abilities become more proficient in adolescence (e.g., Batty & Taylor, 2006; Mondloch, Geldart, Maurer, & Le Grand, 2003; O'Connor, Hamm, & Kirk, 2005).

The use of two age groups allowed to evaluate the robustness and generality of the effects. They were chosen to capture a large developmental window at school age, when face perception should already be holistic in typically developing (TD) children, according to the preceding literature, but perhaps not so (or not as much) in children with ASD. Indeed, cross-sectional studies suggest a reduced age-related improvement in face processing skills beyond childhood in those with ASD compared with TD individuals (Greimel et al., 2014; O'Connor et al., 2005; O'Hearn, Schroer, Minshew, & Luna, 2010; Rump, Giovannelli, Minshew, & Strauss, 2009).

We applied the gaze-contingent mask and window technique to a face discrimination and matching task in children with and without ASD. The goal of our study was twofold.

First, we wanted to provide a more direct evaluation of holistic face processing in ASD. Similar to Van Belle and colleagues (Van Belle, De Graef, Verfaillie, et al., 2010; Van Belle, De Graef, Verfaillie, Rossion, et al., 2010; Van Belle et al., 2011), we manipulated the amount of simultaneously available information by means of a moving mask and window, and we examined the effect on face discrimination and matching abilities. If the performance difference in face perception tasks between children with and without ASD is due to less (efficient) holistic processing in the ASD sample, the gaze-contingent manipulation should have a different impact in both participant groups. Hindering high-resolution sampling of individual features by covering them with a mask would hamper analytical viewing strategies (the natural strategy of the ASD sample) and would interfere to a lesser extent with holistic processing (the natural strategy of the control sample). Likewise, hindering the integration of different facial characteristics (i.e., holistic processing) by means of a foveal window will force both participant groups to rely on analytical processing, which is sometimes thought to be the natural strategy of children with ASD. Therefore, we predict a larger performance difference between children with and without ASD in the mask condition.

Second, we wanted to investigate the eye-movement patterns of children with ASD. General eye-movement parameters, such as fixation duration, number of fixations, or saccade length provide an implicit indication of task difficulty or processing style. Longer fixations, for instance, are often associated with a deeper and more effortful processing, and longer saccades indicate a more ambient viewing style (Holmqvist et al., 2011). In addition to this more cognitive origin, differences in general eye-movement parameters could also stem from oculomotor abnormalities, as suggested using basic laboratory-controlled tasks without social stimuli. For example, some researchers have shown a reduced saccade accuracy in individuals with ASD, which could suggest abnormalities in specialized brain circuits (Schmitt, Cook, Sweeney, & Mosconi, 2014). In addition, in-depth examination of gaze location allows inferences about the critical features used by participants.

Experiment 1

Method

Participants

Two groups of boys without intellectual disability (full-scale [FSIQ], verbal [VIQ], and performance IQ [PIQ] $\geq$ 70) participated in this study. The ASD group was formally diagnosed by a multidisciplinary team or a child psychiatrist according to *DSM–IV–TR* criteria (American Psychiatric Association, 2000). These children were recruited via the Autism Expertise Centre at the University Hospital (n = 15) and via a special needs school for children with ASD (n = 7). Diagnoses were confirmed within the research protocol using the Autism Diagnostic Observation Scale (Gotham, Pickles, & Lord, 2009) in 19 of the 22 cases. The TD comparison group was recruited through mainstream schools, personal contacts, and advertisements. According to an oral or written declaration of their parents, these children had no psychiatric disorder, no language disorder, and no first-degree family member with ASD. Parents reported no concern about the development of their TD child. In addition, only 2 of the 26 TD children scored above the T70 threshold of the Dutch translation (Roeyers, Thys, Druart, De Schryver, & Schittekatte, 2012) of the Social Responsiveness Scale (Constantino, 2002). In both participant groups, intelligence was assessed with an abbreviated version (Sattler, 2001) of the Wechsler Intelligence Scale for Children (WISC–III–R; Wechsler, 1992), which comprised block design, similarities, picture completion, and vocabulary. None of the participants was using neuroleptics, and all children had normal or corrected to normal vision and were Dutch speaking.

In total, 26 TD children and 22 children with ASD participated. Due to technical problems with eye-movement registration, data acquisition was incomplete in 10 participants. We decided to include only participants who finished at least half of the trials, hence excluding two participants with ASD and two TD children. From this total sample, a subsample of 17 TD participants and 17 participants with ASD was selected to create two matched participant groups, groupwise matched based on age and intelligence (VIQ, PIQ, and FSIQ; as demonstrated by the nonsignificant two-sample t tests, see Table 1). Further analyses included the data of these matched participant samples and not of the whole samples.

Task

Experiment 1 used a same–different task, with two faces presented side by side. Participants had to indicate as fast and accurately as possible whether both faces had the same or a different identity by pressing one of the two keyboard buttons (i.e., “1” for “same” and “2” for “different”). Stimuli remained on screen until response. Each trial was preceded by a one-point drift correction (for an illustration of the task, see Figure 1). Ten practice trials were used, and 96 experimental trials. The practice and learning phase both had the same build-up, but faces used in the practice trials were not included in the test phase. Half of the trials were “same” trials and half were “different.” Trial order was fully randomized.

Procedure

After obtaining written informed consent of their parents (and assent of the participants themselves if

Table 1
Participant Characteristics in Both Experiments

	Matched samples						
	ASD (n = 17) only boys			TD (n = 17) only boys			
Experiment 1	*M*	*SD*	Range	*M*	*SD*	Range	*p*
Age	153.18	19.30	128–206	153.71	14.60	132–179	.93
VIQ	104.41	17.00	70–135	110.00	12.00	95–135	.28
PIQ	100.53	13.80	74–134	106.88	10.30	86–120	.14
FSIQ	102.47	12.00	83.5–132	108.44	7.98	93–119	.10
SRS	87.31	30.40	41–133	29.31	20.60	6–71	< .0001
ADOS	4.60	1.30	3–7	N/A	N/A	N/A	N/A

	Matched samples						
	ASD (n = 19) 17 boys, 2 girls			TD (n = 30) 26 boys, 4 girls			
Experiment 2	*M*	SD	Range	*M*	*SD*	Range	*p*
Age	103.79	13.00	87–123	102.27	14.00	79–123	.70
VIQ	102.58	13.80	78–135	108.23	11.60	78–130	.13
PIQ	104.26	15.00	77–134	105.50	13.10	83–134	.76
FSIQ	103.42	12.10	84.5–130.5	106.87	10.40	83.5–128	.30
SRS	92.61	20.10	44–127	32.88	20.40	13–100	< .0001
ADOS	5.11	1.49	2–8	N/A	N/A	N/A	N/A

Note. Means (*M*s), standard deviations (*SD*s), and p values (two-tailed distribution) of a two-sample t test (homoscedasticity assumption checked with F test) for age (depicted in months), full-scale, verbal, and performance IQ (FSIQ, VIQ, and PIQ, respectively), Social Responsiveness Scale (SRS) raw total scores, Autism Diagnostic Observation Scale (ADOS) severity scores (Gotham et al., 2009), and empathy quotients (EQ) and systemizing quotients (SQ) for both participant groups. SRS questionnaires of six participants with ASD (Experiment 1: n = 3, Experiment 2: n = 1) and six TD participants (Experiment 1: n = 1, Experiment 2: n = 5) were either missing or incomplete. ASD = autism spectrum disorder; TD = typically developing.

they were 12 years or older), participants were tested individually in a quiet and darkened room. The height of the chair and chinrest and the positioning of the headband and eye cameras were individually adjusted. After describing the task, the different viewing conditions were presented to participants, using some paper examples. To reduce response time variability, participants' index fingers were already placed on both response buttons before the experiment commenced. After providing the instructions once more, and only when all remaining questions were answered, a nine-point eye-tracker calibration and validation was performed, followed by the practice trials. After completing the practice phase, the test phase started. A short break was provided when necessary, which was always followed by a new eye-tracker calibration and validation procedure. Afterward, participants received a small present and parents got mileage allowance if applicable. Data were collected between December 2009 and December 2012.

Stimuli

Stimuli consisted of frontal view, colored pictures of faces with a neutral expression. Several photographs with slightly different posing—though all neutral expressions of frontal view faces—were taken by the research team to avoid exact copies for reference and target face. Only Caucasian faces of children within the age range of the participant sample were included. In total, photographs of 32 different individuals were used. Lighting conditions were kept constant and nonfacial characteristics were invisible. External facial features (e.g., hair) were cropped with Adobe® Photoshop CS5, respecting the natural face contour. Face stimuli were positioned against a white background, with eyes and mouth at approximately the same position. Target and distracter faces were paired such that face discrimination based on one distinguishable feature (e.g., eye color) was impossible. Faces measured 11.5° × 13°, with a distance of

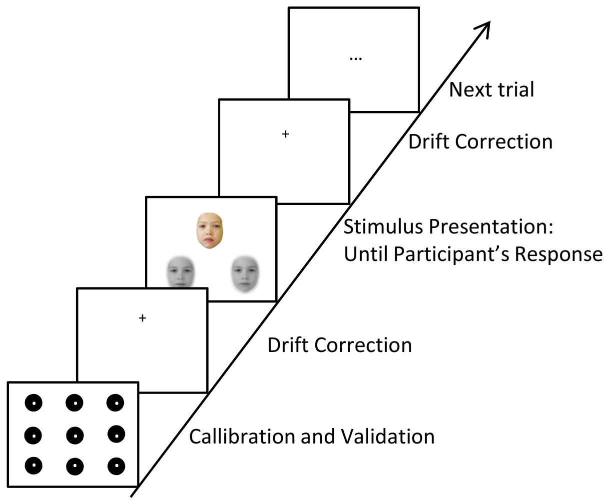

Figure 1. The experiment's procedure (Experiment 2): After the nine-point calibration and validation, the trial started with a one-point drift correction. Three faces were then presented and participants were instructed to indicate fast and accurately which of both match faces had the same identity as the reference face. Available information was manipulated contingent with gaze, and unfixated faces were replaced by the average gray face. (Note that the procedure of Experiment 1 was the same, except for differences in stimuli and task.) [Color figure can be viewed at wileyonlinelibrary.com]

approximately 9.5° between the inner borders of two faces.

The available stimulus information was manipulated in real time depending on where people looked, in three different ways. More specifically, three gaze-contingent viewing conditions were used (see Figure 2). In the full view condition, the fixated face was completely visible. In the mask condition, an elliptical area of approximately 5° × 2.5° surrounding gaze position was covered by a white oval mask. In the window condition, only the 5° × 2.5° elliptical area surrounding gaze position was visible, and the rest of the face was invisible (white cover). Note that the other, nonfixated face was replaced with the average gray face (created by averaging all stimuli and converting the result to gray scale) in every gaze-contingent viewing condition to avoid the presence of a full face in the periphery in window view and to provide a reference for saccade planning with the mask.

Apparatus

The stimuli were displayed using Presentation software on a 20 in. A cathode ray tube (CRT) monitor, with a spatial resolution of 1280 × 1024 and a refresh rate of 100 Hz. Responses were collected with a standard PC and keyboard. Eye movements were recorded monocularly (dominant eye, eye dominance established with look-through-tube test) at a sampling rate of 500 Hz, using the head-mounted EyeLink II system (SR Research, Osgood, ON, Canada). A chinrest was used to restrict the amount of head movements, and viewing distance was kept constant at 60 cm.

Data Preparation and Data Analysis

In general: data preparation. Normality assumptions were checked graphically, taking kurtosis and skewness values into account. If necessary, data were transformed to obtain normal distributions using logarithmical transformations (with natural base) for reaction time, inverse efficiency scores (IES; Townsend & Ashby, 1983), saccade lengths and fixation durations, arcsine transformations for mean proportion correct data, and square root transformations for number and proportion of fixations. We checked for outliers, that is, participants with an average score more than 2 *SD*s smaller or larger than the group's mean performance. For the region of interest (ROI) analyses, participants were considered an outlier if they fixated the background more or less than the group's mean ± 2 *SD*s. Analyses were performed with and without outliers, and differences were reported. A significance level of $p < .05$ (two-sided) was adopted, and effects with a p value between .05 and .10 were indicated as marginally significant. Post hoc evaluation of main effects was performed using Tukey–Kramer corrected contrasts, and interaction effects were further examined using simple main analyses. For all significant effects involving participant group, Cohen's d effect sizes were calculated by dividing the estimated group difference (least square means) by the pooled standard deviation ($\sqrt{[(\sigma_1^2 + \sigma_2^2)/2]}$).

Behavioral data. Reaction times (only the correct trials, expressed in milliseconds) and accuracy data were analyzed. Pearson's correlations between reaction times and proportion correct scores were calculated to check for speed–accuracy trade-offs. IES were calculated by dividing mean reaction times by mean proportion correct scores (per Viewing Condition × Participant), such that lower IES reflected better performance. Reaction times and IES were both analyzed with the Statistical Analysis System (SAS, version 9.3, 2011; SAS Institute Inc., Cary, NC, USA) mixed procedure, and accuracy data with the SAS glimmix procedure (applying the logit link function and a binomial probability distribution). All models included viewing condition

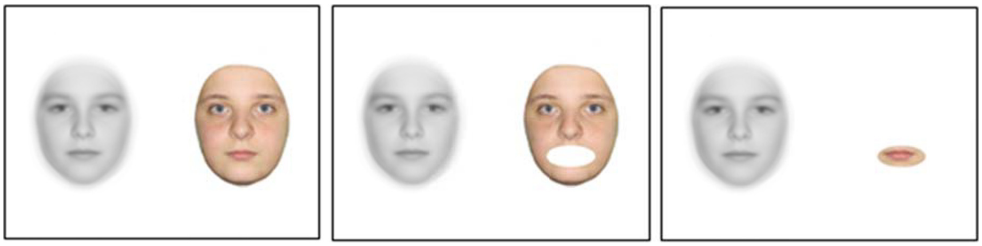

Figure 2. Example of the three gaze-contingently manipulated viewing conditions. Available information was gaze-contingently manipulated: full view condition (left panel), mask condition (middle panel), and window condition (right panel). Unfixated faces were replaced by the average gray face. (The same technique was used in Experiments 1 and 2, but the stimulus configuration was different in both experiments.) [Color figure can be viewed at wileyonlinelibrary.com]

(full, mask, and window view) as within-subjects factor, participant group (ASD and TD) as between-subjects factor, and the interaction between viewing condition and participant group as fixed effects and subject as random factor.

Eye-movement data. General eye-movement parameters (number of fixations, mean fixation durations, and mean saccade lengths) were analyzed with the SAS mixed procedure for repeated measures data, including viewing condition (full, mask, and window view) as within-subjects factor, participant group (ASD and TD) as between-subjects factor, and the interaction between Viewing Condition × Participant Group as fixed effects and subject as random factor. Off-screen fixations were compared between groups using nonparametric tests and excluded from further ROI analyses. ROI assignment was carried out with custom-built Matlab scripts, yielding for every participant the percentage of fixations on the different ROIs, which was then analyzed with the SAS mixed procedure for repeated measures data. ROI (eyes, nose, mouth, rest of the face, and background) and viewing condition (full, mask, and window) were included as within-subjects factor, participant group (ASD and TD) as between-subjects factor, and all two- and three-way interaction effects as fixed effects and subject as random effect. A backward model selection procedure was adopted.

Results

Behavioral Analyses

Accuracy. Overall performance levels were high in the ASD (M = .90, SD = .07) and the TD group (M = .91, SD = .07), and clearly above chance. The main effect of participant group was not significant, $F(1, 32) = 0.34$, $p = .56$, but there was an effect of viewing condition, $F(2, 64) = 10.70$, $p < .0001$, such that full and mask view condition, which did not differ in accuracy, $t(64) = 1.03$, $p = .56$, were both responded more accurately than the window view condition, $t(64) = 4.29$, $p = .0002$ and $t(64) = 3.30$, $p = .004$, respectively. The interaction between participant group and viewing condition was not significant, $F(2, 64) = 0.07$, $p = .93$.

Reaction times (logarithmically transformed). Unsurprisingly, a main effect of viewing condition was found, $F(2, 64) = 221.95$, $p < .0001$, showing that full view trials were responded more rapidly than mask view trials, $t(64) = -5.57$, $p = < .0001$, and that window view trials were responded more slowly than both mask trials, $t(64) = -14.88$, $p < .0001$, and full trials, $t(64) = -20.45$, $p < .0001$. The ASD group responded significantly more slowly than the TD group (d = 0.74), $F(1, 32) = 4.69$, $p = .04$, but the interaction effect between participant group and viewing condition was not significant, $F(2, 64) = 1.92$, $p = .15$ (see Figure 3).

Speed–accuracy trade-off and IES (logarithmically transformed). No evidence for a speed–accuracy trade-off was found: The correlation between

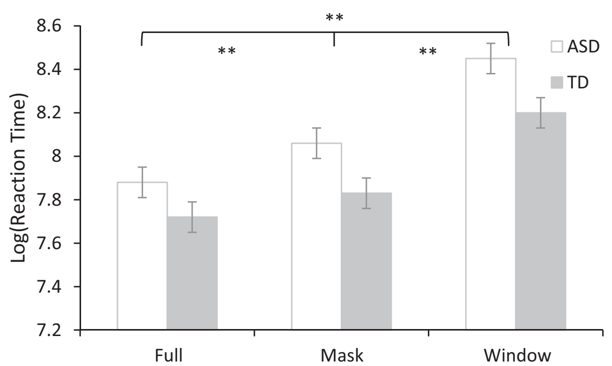

Figure 3. The effect of participant group and viewing condition on logarithmically transformed reaction times. Overall, reaction times for the window viewing condition were larger than for mask or full viewing conditions. The autism spectrum disorder (ASD) group responded generally more slowly than typically developing (TD) participants. Error bars represented standard errors (*SEs*).

reaction time and (arcsine transformed) accuracy was approximately 0, $r(32) = -.02$, $p = .93$. IES demonstrated significantly reduced efficiency in the ASD group compared with the TD group ($d = 0.79$), $F(1, 32) = 5.98$, $p = .02$. There was also a main effect of viewing condition, $F(2, 64) = 76.07$, $p < .0001$. Post hoc tests showed that efficiency scores were higher in full view trials than in both mask, $t(64) = -4.41$, $p < .0001$, and window view trials, $t(64) = -12.18$, $p < .0001$. Efficiency scores of mask and window view trials were also significantly different, $t(64) = -7.77$, $p < .0001$). The interaction effect between viewing condition and participant group was not significant, $F(2, 64) = 0.64$, $p = .62$.

Eye-Movement Analyses

General eye-movement parameters. Participants showed significantly more, $F(2, 64) = 58.33$, $p < .0001$, and longer fixations, $F(2, 64) = 13.43$, $p < .0001$, in the window viewing condition than in the mask or full viewing conditions, but no effect of viewing condition was found on saccade length, $F(2, 64) = 1.98$, $p = .15$. In addition, results revealed more fixations ($d = 0.48$), $F(1, 32) = 9.04$, $p = .01$, and longer saccades in the ASD group ($d = 0.29$), $F(1, 32) = 4.12$, $p = .05$, but no effect of group on fixation duration, $F(1, 32) = 0.74$, $p = .40$. The interaction effect between participant group and viewing condition was not significant for number of fixations, $F(2, 64) = 0.57$, $p = .57$, for fixation duration, $F(2, 64) = 1.60$, $p = .21$, or for saccade length, $F(2, 64) = 0.23$, $p = .80$.

Fixation locations. ROI analyses showed an overall low proportion off-screen fixations (ASD: $M = .01$, $SD = .02$; TD: $M = .01$, $SD = .01$), although slightly higher in the ASD sample, Wilcoxon $Z(32) = 2.12$, $p = .04$. Off-screen fixations were excluded from further ROI analyses, which showed no main effect of viewing condition, $F(2, 66) = 0.33$, $p = .72$, or of participant group, $F(1, 32) = 0.47$, $p = .50$. The main effect of ROI was significant, $F(4, 128) = 165.09$, $p < .0001$. As shown in the heat maps (see Figure 4), the highest proportion of fixations was on the eyes, followed by the rest of the face, the background, and the nose, and the lowest proportions of fixations was on the mouth (contrasts with $ps < .001$). Furthermore, the interaction between ROI and viewing condition proved significant, $F(8, 264) = 2.70$, $p = .01$. Most interestingly, the interaction effect between ROI and participant group was significant, $F(4, 128) = 4.94$, $p = .001$ (see Figure 4, below). Post hoc simple main analysis suggested fewer fixations on eyes in the ASD group compared with the TD sample ($d = -0.61$), $F(1, 128) = 5.37$, $p = .02$, and more fixations on noses ($d = 0.65$), $F(1, 128) = 7.26$, $p = .01$, and on the rest of the face ($d = 0.79$), $F(1, 128) = 6.14$, $p = .01$, but no significant group differences were found for mouth ($d = -0.10$), $F(1, 128) = 0.01$, $p = .91$, or background ($d = -0.33$), $F(1, 128) = 1.46$, $p = .23$. Neither the two-way interaction between viewing condition and participant group, $F(2, 64) = 0.01$, $p = .99$, nor the three-way interaction between ROI, viewing condition, and participant group were significant, $F(8, 256) = 0.08$, $p = .99$.

Experiment 2

A more straightforward simultaneous matching-to-sample task was applied to a younger sample of boys and girls, aged 6–10. The strategy for participant recruitment and diagnosis, procedure, stimuli, and apparatus were mostly identical to Experiment 1. Only the differences will be mentioned below.

Method

Participants

Selection procedure and inclusion and exclusion criteria were the same as in Experiment 1, except that (a) a sample of boys and girls was included in Experiment 2, whereas only boys participated in Experiment 1, and (b) 6- to 10-year-olds were tested in Experiment 2 compared to 10- to 14-year-olds in Experiment 1. In total, 39 TD children (29 boys, 10 girls) and 21 children with ASD (18 boys, 3 girls) participated. Due to technical problems with eye-movement registration, data acquisition was incomplete in 11 participants. We decided to include only participants who finished at least half of the trials, hereby excluding two participants with ASD and one TD child. From this total sample, two matched subsamples of 30 TD participants (26 boys, 4 girls) and 19 children with ASD (17 boys, 2 girls) were selected to create two participant groups which were groupwise matched on age, gender ratio, and intelligence (see Table 1). Analyses were performed on these matched participant groups and not on whole samples (for detailed participant characteristics, refer to Table 1).

Task

Experiment 2 used a simultaneous matching-to-sample task. Every trial contained three faces: one reference face centered in the top screen half and two probe face presented side by side on the bottom

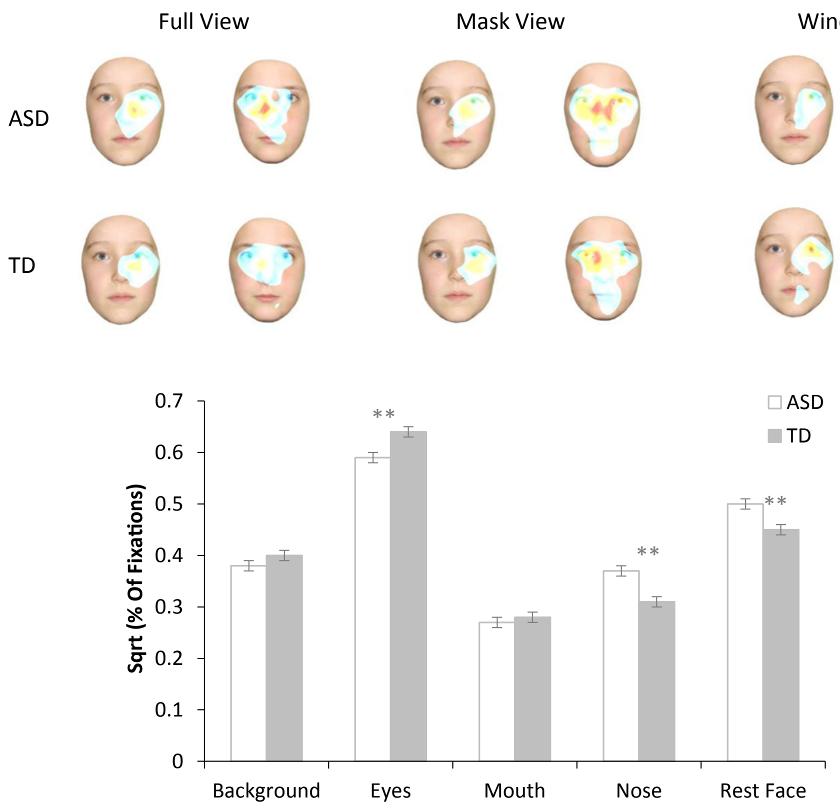

Figure 4. Above: Heat maps of fixation durations for the autism spectrum disorder (ASD) and the typically developing (TD) sample (generated by iMAP, version 3, see Caldara & Miellet, 2011). Below: Region of interest (ROI) analyses on the (square root transformed) proportions of fixations showed that the ASD group made significantly fewer fixations at eyes and more at nose and the background compared with the TD group. Error bars represented standard errors (SEs). [Color figure can be viewed at wileyonlinelibrary.com]

screen half. Participants had to indicate as fast and accurately as possible which of both probe faces (target or distracter face, presented randomly left and right) had the same identity as the reference face by pressing one of two keyboard buttons (i.e., "s" for the face on the left side and "k" for the face on the right sight, corresponding with the key positions on an AZERTY keyboard). The experiment consisted of 10 practice trials and 84 experimental trials, divided into three blocks, each consisting of trials of all viewing conditions. Trial order was fully randomized.

Procedure

The general procedure in Experiments 1 and 2 was the same. Data were collected between September 2010 and December 2012.

Stimuli

The construction of the facial stimuli was the same as in Experiment 1. In total, pictures of 28 different individuals were included. Faces measured 10.5° × 8.5° with a distance of 7.27° between the two probe faces. As in Experiment 1, the available stimulus information was manipulated in real-time depending on where people looked, using three viewing conditions (see Figure 2). In the full view condition, the fixated face was completely visible. In the mask and window condition, a gaze-contingent mask or window (subtending 2.5° × 1.5°) was applied to the probe faces but not the reference face. The nonfixated probe face was covered by the average gray scale face in every viewing condition. The reference face remained visible in full view, also when not fixated.

Apparatus

Apparatus was the same as in Experiment 1, except for the software used for stimulus presentation (Matlab in Experiment 2, Presentation in Experiment 1), and the used eye-gaze recording system (remote Eyelink 1000 in Experiment 2, head-mounted Eyelink 2 in Experiment 1). A chinrest was used to restrict the amount of head movements.

Data and Data Analysis

Data preparation and statistical analyses were identical to Experiment 1. (Excluding the small number of female participants from the analyses did not yield meaningful different results.)

Results

Behavioral Data

Accuracy. Overall performance levels were high (ASD: $M = .89$, $SD = .10$; TD: $M = .92$, $SD = .10$) and clearly above chance. The main effect of participant group was not significant, $F(1, 47) = 1.36$, $p = .25$. (Note that one TD participant performed at chance level [$M = .51$], but none of the further [accuracy, reaction times, or IES] analyses yielded different results when we excluded that participant.) The main effect of viewing condition was significant, $F(2, 94) = 62.28$, $p < .0001$, such that full view trials were responded more accurately than both mask, $t(94) = 2.35$, $p = .05$, and window trials, $t(94) = 9.99$, $p < .0001$. The difference between mask and window trials was also significant, $t(94) = 8.05$, $p < .0001$. The interaction between viewing condition and participant group was not significant, $F(1, 94) = 0.15$, $p = .74$.

Reaction times (logarithmically transformed). As expected, the effect of viewing condition was significant, $F(2, 94) = 329.12$, $p < .0001$. Participants responded generally slower at window view trials than at mask, $t(94) = -19.76$, $p < .0001$, or full view trials, $t(94) = -24.44$, $p < .0001$, and reaction time between mask and full view trials were also significantly different, $t(94) = -4.73$, $p < .0001$. Overall, the ASD sample tended to respond more slowly than the comparison group ($d = 0.52$), $F(1, 47) = 3.04$, $p = .09$. The interaction between viewing condition and participant group was significant, $F(2, 94) = 4.27$, $p = .02$ (see Figure 5). Post hoc analyses revealed that the ASD group was especially slower than the TD group in the full viewing condition ($d = 0.69$), $F(1, 94) = 5.06$, $p = .03$, and in the mask condition ($d = 0.53$), $F(1, 94) = 3.51$, $p = .06$, but not in the window condition ($d = 0.22$), $F(1, 94) = 0.87$, $p = .35$.

Speed–accuracy trade-off and IES (logarithmically transformed). Participants with higher accuracy rates responded more slowly, $r(47) = .27$, $p = .06$, and especially so in the TD group, $r(28) = .43$, $p = .02$, which could suggest a speed–accuracy trade-off. In addition, the ASD group responded less efficiently than the TD comparison sample ($d = 0.69$), $F(1, 47) = 5.51$, $p = .02$. Again, the main effect of viewing condition was significant, $F(2, 94) = 142.02$, $p < .0001$, with full view trials being responded more efficiently than both mask, $t(94) = -3.88$, $p = .0006$, and window view trials, $t(94) = -16.14$, $p < .0001$. The difference between mask and window view trials was also significant, $t(94) = -12.26$, $p < .0001$. The interaction effect between viewing condition and participant group was not significant, $F(2, 94) = 1.38$, $p = .26$.

Eye-Movement Analyses

General eye-movement parameters. A main effect of viewing condition was found for number of fixations, $F(2, 94) = 71.03$, $p < .0001$, for fixation durations, $F(2, 94) = 36.67$, $p < .0001$, and for saccade length, $F(2, 94) = 4.45$, $p = .01$, but the exact nature of the effect differed between the different variables. The number of fixations was significantly larger for window than for mask, $t(94) = -7.70$, $p < .0001$, or full view trials, $t(94) = -11.73$, $p < .0001$, and higher in the mask than in the full viewing condition, $t(94) = 4.03$, $p = .0003$. Fixation duration was shorter in mask view trials than in full, $t(94) = 6.06$, $p < .0001$, or window view trials, $t(94) = -8.27$, $p < .0001$, which both did not differ in fixation duration, $t(94) = -2.21$, $p = .07$. Saccades were significantly longer in the full viewing condition compared with mask trials, $t(94) = 2.95$, $p = .01$. The difference between full and window

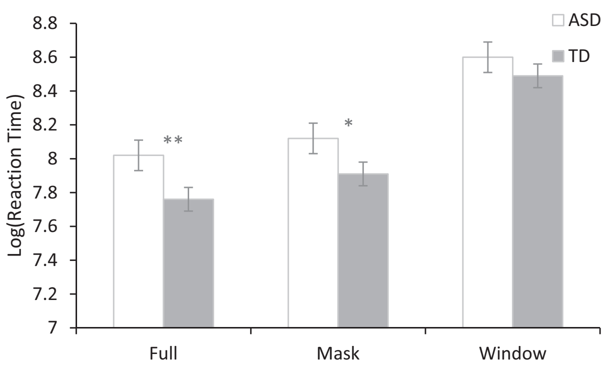

Figure 5. The effect of viewing condition and participant group on logarithmically transformed reaction time. The autism spectrum disorder (ASD) group responded especially more slowly than the typically developing (TD) group in the full viewing condition and tended to do so in the mask viewing condition. Error bars represented standard errors (*SEs*).

viewing trials, $t(94) = 1.12$, $p = .50$, or between window and mask trials was not significant, $t(94) = -1.83$, $p = .17$. The main effect of participant group was not significant for number of fixations, $F(1, 47) = 2.77$, $p = .10$, for fixation duration, $F(1, 47) = 0.94$, $p = .34$, or for saccade length, $F(1, 47) = 0.65$, $p = .42$. The interaction between viewing condition and participant group was not significant for number of fixations, $F(2, 94) = 0.30$, $p = .74$, for fixation duration, $F(2, 94) = 0.05$, $p = .95$, or for saccade length, $F(2, 94) = 0.20$, $p = .82$.

Fixation locations. ROI analyses showed an overall low proportion off-screen fixations (ASD: $M = .01$, $SD = .01$; TD group: $M = .002$, $SD = .003$), marginally higher in the ASD sample than in the TD group, Wilcoxon $Z(47) = 1.82$, $p = .07$. Off-screen fixations were excluded from further ROI analyses, which showed no main effect for viewing condition, $F(2, 96) = 0.03$, $p = .97$, or for participant group, $F(1, 47) = 0.45$, $p = .51$. The main effect of ROI was significant, $F(4, 188) = 224.05$, $p < .0001$ (see Figure 6), revealing the highest proportion of fixations on eyes, then on the rest of the face, nose, and lowest proportions of fixations on the background and mouth. Post hoc Tukey–Kramer corrected contrasts were all significant (with ps < .0001), but the contrast between background and mouth, $t(188) = -1.20$, $p = .74$. The interaction between ROI and viewing condition was marginally significant, $F(8, 384) = 1.75$, $p = .09$. Most interestingly, the interaction effect between ROI and participant group proved significant, $F(4, 188) = 6.12$, $p = .0001$ (see Figure 6, upper graph). Post hoc simple main analysis suggested more fixations on eyes ($d = 0.47$), $F(1, 188) = 12.47$, $p = .001$, and on the rest of the face ($d = 0.91$), $F(1, 188) = 5.77$, $p = .02$, in the ASD group compared with the TD sample, and fewer on the background ($d = -0.22$), $F(1, 188) = 3.23$, $p = .07$, but no differences were found for mouths ($d = -0.24$), $F(1, 188) = 1.52$, $p = .22$, or noses ($d = -0.33$), $F(1, 188) = 1.96$, $p = .16$. Neither the two-way viewing Condition × Participant Group interaction, $F(2, 94) = 0.07$, $p = .93$, nor the three-way interaction between ROI, viewing condition, and participant group were significant, $F(8, 376) = 0.15$, $p = .99$.

Four outliers were found, of which three TD participants with more than 75% of fixations on the background (i.e., the white area in between the faces). After excluding these outliers, the interaction effect between ROI and group remained significant, $F(4, 172) = 10.35$, $p < .0001$, but its nature changed (see Figure 6, lower graph). The outliers excluded data also showed that the ASD sample fixated more on the rest of the face ($d = 1.10$), $F(1, 172) = 7.87$, $p = .01$, and tended to fixate more on the eyes ($d = 0.30$), $F(1, 172) = 3.03$, $p = .08$, compared with the TD group. However, we now found more fixations on background in the ASD sample ($d = 0.45$), $F(1, 172) = 4.39$, $p = .04$, and fewer fixations on mouth ($d = -0.39$), $F(1, 172) = 5.85$, $p = .02$, and nose ($d = -0.90$), $F(1, 172) = 20.22$, $p < .0001$, compared to the TD group.

General Discussion

We wanted to provide deeper insight into two core aspects of face processing in children with ASD: by directly evaluating the strength of holistic face processing and by examining preferential looking patterns. We therefore applied the gaze-contingent mask and window technique to a face discrimination (Experiment 1) and face matching (Experiment 2) paradigm in two age groups of children with ASD and in matched TD comparison samples.

Face Processing Difficulties in Children With ASD

Experiments 1 and 2 demonstrated (slightly) slower and less efficient face discrimination and matching in the ASD group compared with the matched TD group. A more effortful, attention-demanding face processing style was also reflected in their eye movements, as the ASD group made more fixations (associated with their longer reaction times). Taken together, these findings parallel the previously demonstrated poorer performance on face discrimination and recognition tasks in individuals with ASD, which appears especially the case when a memory component is involved (see review by Weigelt et al., 2012). Although our simultaneous same–different and matching-to-sample task did not impose strong memory demands, the moving mask and window conditions do necessitate some memory encoding, as the available information is restricted. Anyhow, the ASD group did not display a general face processing deficit, as they did not perform less accurately but performed merely slower and less efficiently.

Whole or Hole? The Effect of Viewing Condition

Gaze-contingent stimulus manipulations allow for the online manipulation of the participant's visual input based on their actual fixation position.

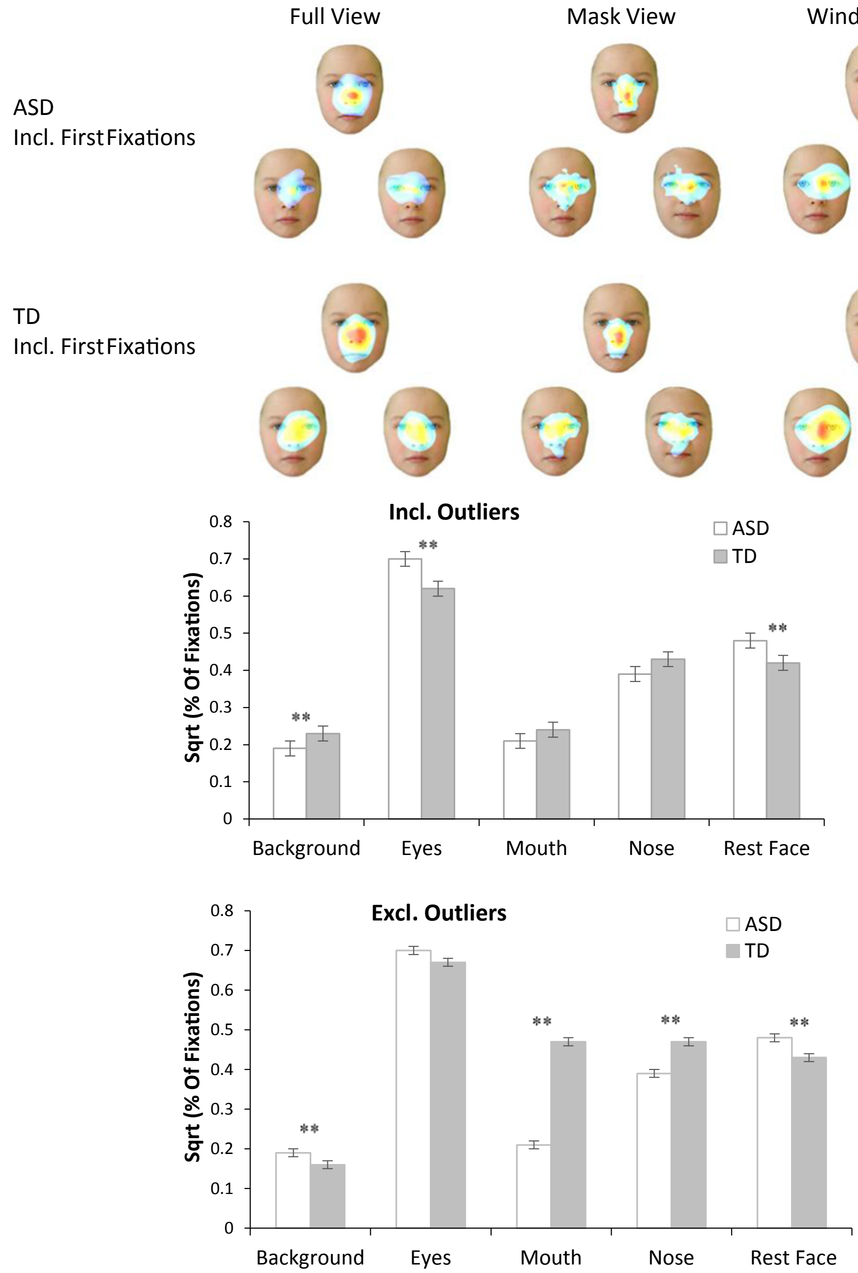

Figure 6. Above: Heat maps of fixation durations for the autism spectrum disorder (ASD) and the typically developing (TD) sample (generated by iMAP, version 3, see Caldara & Miellet, 2011). Below: Region of interest (ROI) analyses on the (square root transformed) proportions of fixations showed a significant interaction effect between participant group and ROI. The exact nature of this interaction did depend on the inclusion (upper graph) or exclusion (lower graph) of the outliers (whose fixation pattern was characterized by a large number of fixations on the background). Error bars represented standard errors (*SE*s). [Color figure can be viewed at wileyonline-library.com]

Although participants' visual input was restricted to the fixated facial characteristic in the moving window condition, participants had access to all visual information in their periphery but not to the fixated feature in the moving mask condition. The current study showed a strong effect of viewing condition in both experiments. Unsurprisingly, full view trials were overall responded faster, more accurately, and more efficiently than mask or window view trials, reflecting worse performances when the available information was limited. Although fixation locations appeared remarkably similar across viewing conditions, general eye-movement parameters were substantially affected by viewing condition. Consistent with the reaction time data, participants generally used more and longer fixations in the moving window condition, suggesting an increased attention and reflecting a deeper, more effortful (compensatory) information processing in that condition (Holmqvist et al., 2011; for similar findings, see Maw & Pomplun, 2004). The saccade amplitude data were mixed: no effect of viewing condition was found in Experiment 1 (similar to Maw & Pomplun, 2004), but Experiment 2 showed the longest saccades in full view trials, which could suggest more ambient or global scanning (Holmqvist et al., 2011).

Reduced Holistic Face Processing Style in Young Children With ASD

Although no evidence was found for an interaction between viewing condition and participant group in the 10- to 14-year-olds (Experiment 1), this interaction effect was significant in the 6- to 10-year-olds (Experiment 2), revealing that the younger ASD sample responded particularly more slowly than the matched TD group on full and mask view trials, but not on window view trials.

According to the logic of the moving mask and moving window paradigm explained in the Introduction, our current data therefore reveal an attenuated bias toward holistic face processing in 6- to 10-year-old children with ASD but no problems with analytical face perception. Participants with ASD proved especially slower than the TD group when faces were presented naturally (full viewing condition) or with a moving mask. Under the full viewing condition, participants could use their spontaneous strategies to process the available local and global information. The mask hindered high-resolution sampling of detailed local information and provided only global-level information, hampering analytical processing. However, the children with ASD did not experience problems when the moving window restricted the visible area and only provided local-level information, available for detailed analytical processing (but insufficient to process faces holistically). Although face processing generally relies on the interplay between holistic and analytical processing (i.e., global and local), our data provided direct evidence for a reduced holistic face processing in the younger ASD sample.

No evidence for a general holistic processing deficit was found: Overall accuracy levels were high, and the interaction between participant group and viewing condition did not impact accuracy nor efficiency. The current findings are consistent with a meta-analysis, which demonstrated that individuals with ASD are merely slower in capturing the global picture, especially if there is also (incongruent) local information present, but do not show a general global processing deficit (Van der Hallen, Evers, Brewaeys, Van den Noortgate, & Wagemans, 2015). Taken together, this also parallels a theoretical shift in the local–global processing literature in ASD, which now defines the processing deficit in individuals with and without ASD in terms of a different preference, instead of an inability (Happé & Frith, 2006; Mottron et al., 2006). Although these local–global processing theories merely focus on nonsocial perception (but see Frith, 1989; Frith & Happé, 1994, for the link between central coherence and social insight), this study appears to support atypical, less globally oriented face processing strategies in ASD, at least under certain circumstances.

The Development of Face Processing

Both Experiments 1 and 2 showed that full view trials were responded fastest and most accurately, after mask and window view trials, which is consistent with previous research in TD adults (Van Belle, De Graef, Verfaillie, et al., 2010; Van Belle, De Graef, Verfaillie, Rossion, et al., 2010). This challenges the assumption of a default analytical face processing mode in children, but rather contributes to the conviction of a holistic face processing style both in children and adults (Crookes & McKone, 2009; Turati et al., 2010).

Interestingly, subtle differences in face processing style were found in the younger sample with ASD. Although no evidence for an atypical holistic face processing style was found in 10- to 14-year-olds with ASD, the 6- to 10-year-old sample with ASD did show increased analytical face processing. Previous facial emotion and facial identity studies have suggested a developmental delay in children with ASD, without a "typical" age-related improvement of those skills (Greimel et al., 2014; O'Connor et al., 2005; O'Hearn et al., 2010; Rump et al., 2009). However, none of these developmental studies focused on holistic or analytical face processing in ASD.

The current pattern of results showed holistic face processing problems in the 6- to 10-year-olds with ASD, which seemed to disappear in the 10- to 14-year-olds. Indeed, impairments in older children with ASD are sometimes more subtle compared with younger individuals (e.g., for emotion recognition: Harms, Martin, & Wallace, 2010; for grouping and dynamic attention: O'Hearn, Franconeri, Wright, Minshew, & Luna, 2013). In general, this kind of developmental pattern could reflect (cognitively mediated) compensation mechanisms, or—may be—a delayed development, converging to typical development. However, such conclusions are limited by the cross-sectional nature of our study and by the use of two different tasks in both age groups (discrimination vs. matching task).

Atypical Preferential Viewing Patterns in Children With ASD?

The ASD and TD group shared a strong preference for the upper face half over the lower face half, which is consistent with previous work that illustrates the importance of the eyes region for face processing (e.g., Ellis, Shepherd, & Davies, 1979). However, differences could be noted too: Consistent with previous studies (for a see meta-analysis, see Papagiannopoulou et al., 2014), ROI analyses revealed that the 10- to 14-year-old ASD group made fewer fixations at eyes, and more at the nose and the rest of the face, compared with the TD group. The fixation pattern of the younger 6- to 10-year-old sample with ASD was slightly different. After exclusion of the outliers, the ASD group showed slightly more fixations at eyes, at the background, and at the rest of the face, and fewer fixations at mouth and nose, compared with the TD group. Visual exploration suggests more dense heat maps in the ASD group, with fixations located in a rather small area centered around the fixation peak. The TD comparison group, however, used a somewhat broader area of interest, and showed fixation patterns with a peak centered on the same location as the ASD sample, but more extended toward the mouth region. As ROI analyses use proportional fixation data, a less dense fixation pattern with more fixations at mouths automatically implies fewer fixations at the eyes, compared to the ASD sample. Hence, the atypical preferential viewing pattern of the younger ASD group, which first seemed to contradict previous work, can be understood. Taken together, this atypical viewing pattern in the ASD sample could suggest that they do not flexibly broaden their scope of attention toward other facial characteristics, whereas the TD comparison group automatically attunes fixation orientation to the task demands, which seems to go hand in hand with better performance.

Conclusion

In sum, applying the gaze-contingent mask and window technique to a face discrimination and matching task in two age groups of children with and without ASD, the present study did not support a general holistic face processing deficit in children with ASD. However, current results revealed a reduced holistic face processing bias in the younger 6- to 10-year-old children with ASD but not in the older sample aged 10- to 14-year-old. Furthermore, eye-movement analyses pointed both toward similarities and differences across both participant groups.

References

American Psychiatric Association. (2000). *Diagnostic and Statistical Manual of Mental Disorders (4th ed., text revision)*. Washington, DC: Author.

Ames, C., & Fletcher-Watson, S. (2010). A review of methods in the study of attention in autism. *Developmental Review*, *30*, 52–73. doi:10.1016/j.dr.2009.12.003

Batty, M., & Taylor, M. J. (2006). The development of emotional face processing during childhood. *Developmental Science*, *9*, 207–220. doi:10.1111/j.1467-7687.2006.00480.x

Behrmann, M., Avidan, G., Leonard, G. L., Kimchi, R., Luna, B., Humphreys, K., & Minshew, N. (2006). Configural processing in autism and its relationship to face processing. *Neuropsychologia*, *44*, 110–129. doi:10.1111/j.1467-7687.2006.00480.x

Behrmann, M., Richler, J. J., Avidan, G., & Kimchi, R. (2015). Holistic face perception. In J. Wagemans (Ed.), *Oxford handbook of perceptual organization* (pp. 758–774) Oxford, UK: Oxford University Press.

Bruce, V., & Young, A. W. (2012). *Face perception*. London, UK; New York, NY: Psychology Press.

Busigny, T., Van Belle, G., Jemel, B., Hosein, A., Joubert, S., & Rossion, B. (2014). Face-specific impairment in holistic perception following focal lesion of the right anterior temporal lobe. *Neuropsychologia*, *56*, 312–333. doi:10.1016/j.neuropsychologia.2014.01.018

Constantino, J. N. (2002). *The Social Responsiveness Scale*. Los Angelos: Western Psychological Services.

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

Crookes, K., & McKone, E. (2009). Early maturity of face recognition: No childhood development of holistic processing, novel face encoding, or face-space. *Cognition*, *111*, 219–247. doi:10.1016/j.cognition.2009.02.004

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

de Heering, A., Houthuys, S., & Rossion, B. (2007). Holistic face processing is mature at 4 years of age: Evidence from the composite face effect. *Journal of Experimental Child Psychology*, *96*, 57–70. doi:10.1016/j.jecp.2006.07.001

Deruelle, C., Rondan, C., Salle-Collemiche, X., Bastard-Rosset, D., & Da Fonseca, D. (2008). Attention to low- and high-spatial frequencies in categorizing facial identities, emotions and gender in children with autism. *Brain and Cognition*, *66*, 115–123. doi:10.1016/j.bandc.2007.06.001

Di Martino, A., Uddin, L. Q., Sklar, A. B., Castellanos, F. X., & Milham, M. P. (2009). Functional brain correlates of social and nonsocial processes in autism spectrum disorders: An activation likelihood estimation meta-analysis. *Biological Psychiatry*, *65*, 64–74. doi:10.1016/j.biopsych.2008.09.022

Ellis, H. D., Shepherd, J. W., & Davies, G. M. (1979). Identification of familiar and unfamiliar faces from internal and external features: Some implications for theories of face recognition. *Perception*, *8*, 431–439. doi:10.1068/p080431

Falck-Ytter, T., Bölte, S., & Gredebäck, G. (2013). Eye tracking in early autism research. *Journal of Neurodevelopmental Disorders*, *5*, 1–13. doi:10.1186/1866-1955-5-28

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

Field, T. M., Cohen, D., Garcia, R., & Greenberg, R. (1984). Mother-stranger face discrimination by the newborn. *Infant Behavior and Development*, *7*, 19–25. doi:10.1016/S0163-6383(84)80019-3

Frith, U. (1989). *Autism: Explaining the enigma*. Oxford, UK: Blackwell.

Frith, U., & Happé, F. (1994). Autism—beyond theory of mind. *Cognition*, *50*, 115–132. doi:10.1016/0010-0277(94)90024-8

Golarai, G., Grill-Spector, K., & Reiss, A. L. (2006). Autism and the development of face processing. *Clinical Neuroscience Research*, *6*, 145–160. doi:10.1016/j.cnr.2006.08.001

Goren, C. C., Sarty, M., & Wu, P. Y. (1975). Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics*, *56*, 544–549.

Gotham, K., Pickles, A., & Lord, C. (2009). Standardizing ADOS scores for a measure of severity in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *39*, 693–705. doi:10.1007/s10803-008-0674-3

Greimel, E., Schulte-Ruether, M., Kamp-Becker, I., Remschmidt, H., Herpertz-Dahlmann, B., & Konrad, K. (2014). Impairment in face processing in autism spectrum disorder: A developmental perspective. *Journal of Neural Transmission*, *121*, 1171–1181. doi:10.1007/s00702-014-1206-2

Happé, F., & Booth, R. D. L. (2008). The power of the positive: Revisiting weak coherence in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, *61*, 50–63. doi:10.1080/17470210701508731

Happé, 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. doi:10.1007/s10803-005-0039-0

Harms, M., Martin, A., & Wallace, G. L. (2010). Facial emotion recognition in autism spectrum disorders: A review of behavioral and neuroimaging studies. *Neuropsychology Review*, *20*, 290–322. doi:10.1007/s11065-010-9138-6

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*, 223–233. doi:10.1016/S1364-6613(00)01482-0

Hobson, R. P., Ouston, J., & Lee, A. (1988). What's in a face? The case of autism. *British Journal of Psychology*, *79*, 441–453. doi:10.1111/j.2044-8295.1988.tb02745.x

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., & Van De Weijer, J. (2011). *Eye tracking. A comprehensive guide to methods and measures*. Oxford, UK: Oxford University Press.

Jemel, B., Mottron, L., & Dawson, M. (2006). Impaired face processing in autism: Fact or artifact? *Journal of Autism and Developmental Disorders*, *36*, 91–106. doi:10.1007/s10803-005-0050-5

Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, *40*, 1–19. doi:10.1016/0010-0277(91)90045-6

Kanwisher, N. (2006). Neuroscience—what's in a face? *Science*, *311*, 617–618. doi:10.1126/science.1123983

Kanwisher, N. G., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience*, *17*, 4302–4311. doi:10.1098/rstb.2006.1934

Maurer, D., Grand, R. L., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences*, *6*, 255–260. doi:10.1016/S1364-6613(02)01903-4

Maw, N. N., & Pomplun, M.. (2004). Studying human face recognition with the gaze-contingent window technique. In K. Forbus, D. Gentner, T. Regier (Eds.), *Proceedings of the Twenty-Sixth Annual Meeting of the Cognitive Science Society, 2004, Chicago, IL* (pp. 927–932). Mahwah, NJ: Erlbaum.

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Attention, Perception & Psychophysics*, *17*, 578–586. doi:10.3758/BF03203972

Mondloch, C. J., Geldart, S., Maurer, D., & Le Grand, R. (2003). Developmental changes in face processing skills. *Journal of Experimental Child Psychology*, *86*, 67–84. doi:10.1016/S0022-0965(03)00102-4

Mondloch, C. J., Pathman, T., Maurer, D., Le Grand, R., & de Schonen, S. (2007). The composite face effect in six-year-old children: Evidence of adult-like holistic face processing. *Visual Cognition*, *15*, 564–577. doi:10.1080/13506280600859383

Mottron, L., & Burack, J. A. (2001). Enhanced perceptual functioning in the development of autism. In J. A. Burack, T. Charman, N. Yirmiya & P. R. Zelazo (Eds.), *The development of autism: Perspectives from theory and research* (pp. 131–148). Mahwah, NJ: Erlbaum.

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders*, *36*, 27–43. doi:10.1007/s10803-005-0040-7

O'Connor, K., Hamm, J. P., & Kirk, I. J. (2005). The neurophysiological correlates of face processing in adults and children with Asperger's syndrome. *Brain and Cognition*, *59*, 82–95. doi:10.1016/j.bandc.2005.05.004

O'Hearn, K., Franconeri, S., Wright, C., Minshew, N., & Luna, B. (2013). The development of individuation in autism. *Journal of Experimental Psychology: Human Perception and Performance*, *39*, 494–509. doi:10.1037/a0029400

O'Hearn, K., Schroer, E., Minshew, N., & Luna, B. (2010). Lack of developmental improvement on a face memory task during adolescence in autism. *Neuropsychologia*, *48*, 3955–3960. doi:10.1016/j.neuropsychologia.2010.08.024

Papagiannopoulou, E. A., Chitty, K. M., Hermens, D. F., Hickie, I. B., & Lagopoulos, J. (2014). A systematic review and meta-analysis of eye-tracking studies in children with autism spectrum disorders. *Social Neuroscience*, *9*, 610–632. doi:10.1080/17470919.2014.934966

Pellicano, E., & Rhodes, G. (2003). Holistic processing of faces in preschool children and adults. *Psychological Science*, *14*, 618–622. doi:10.1046/j.0956-7976.2003.psci_1474.x

Piepers, D. W., & Robbins, R. A. (2012). A review and clarification of the terms "holistic," "configural," and "relational" in the face perception literature. *Frontiers in Perception Science*, *3*, 559. doi:10.3389/fpsyg.2012.00559

Roeyers, H., Thys, M., Druart, C., De Schryver, M., & Schittekatte, M. (2012). *SRS: Screeningslijst voor autismespectrum stoornissen*. Amsterdam, The Netherlands: Hogrefe.

Rossion, B. (2008). Picture-plane inversion leads to qualitative changes of face perception. *Acta Psychologica*, *128*, 274–289. doi:10.1016/j.actpsy.2008.02.003

Rossion, B. (2009). Distinguishing the cause and consequence of face inversion: The perceptual field hypothesis. *Acta Psychologica*, *132*, 300–312. doi:10.1016/j.actpsy.2009.08.002

Rossion, B. (2013). The composite face illusion: A whole window into our understanding of holistic face perception. *Visual Cognition*, *21*, 139–253. doi:10.1080/13506285.2013.772929

Rump, K. M., Giovannelli, J. L., Minshew, N. J., & Strauss, M. S. (2009). The development of emotion recognition in individuals with autism. *Child Development*, *80*, 1434–1447. doi:10.1111/j.1467-8624.2009.01343.x

Sasson, N. J. (2006). The development of face processing in autism. *Journal of Autism and Developmental Disorders*, *36*, 381–394. doi:10.1007/s10803-006-0076-3

Sattler, J. M. (2001). *Assessment of children: Cognitive applications* (4th ed.). San Diego, CA: Jerome M. Sattler.

Schmitt, L. M., Cook, E. H., Sweeney, J. A., & Mosconi, M. W. (2014). Saccadic eye movement abnormalities in autism spectrum disorder indicate dysfunctions in cerebellum and brainstem. *Molecular Autism*, *5*, 47–59. doi:10.1186/2040-2392-5-47

Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology*, *46*, 225–245.

Tang, J., Falkmer, M., Horlin, C., Tan, T., Vaz, S., & Falkmer, T. (2015). Face recognition and visual search strategies in autism spectrum disorders: Amending and extending a recent review by Weigelt et al. *PLoS One*, *10*. doi:10.1371/journal.pone.0134439

Teunisse, J. P., & de Gelder, B. (2003). Face processing in adolescents with autistic disorder: The inversion and composite effects. *Brain and Cognition*, *52*, 285–294. doi:10.1016/S0278-2626(03)00042-3

Thompson, P. (1980). Margaret Thatcher: A new illusion. *Perception*, *9*, 483–484. doi:10.1068/p090483

Townsend, J. T., & Ashby, F. G. (1983). *The stochastic modeling of elementary psychological processes*. Cambridge, UK: Cambridge University Press.

Turati, C., Di Giorgio, E., Bardi, L., & Simion, F. (2010). Holistic Face Processing in Newborns, 3-Month-Old Infants, and Adults: Evidence From the Composite Face Effect. *Child Development*, *81*, 1894–1905. https://doi.org/10.1111/j.1467-8624.2010.01520.x

Van Belle, G., Busigny, T., Lefèvre, P., Joubert, S., Felician, O., Gentile, F., & Rossion, B. (2011). Impairment of holistic face perception following right occipito-temporal damage in prosopagnosia: Converging evidence from gaze-contingency. *Neuropsychologia*, *49*, 3145–3150. doi:10.1016/j.neuropsychologia.2011.07.010

Van Belle, G., De Graef, P., Verfaillie, K., Busigny, T., & Rossion, B. (2010). Whole not hole: Expert face recognition requires holistic perception. *Neuropsychologia*, *48*, 2620–2629. doi:10.1016/j.neuropsychologia.2010.04.034

Van Belle, G., De Graef, P., Verfaillie, K., Rossion, B., & Lefevre, P. (2010). Face inversion impairs holistic perception: Evidence from gaze-contingent stimulation. *Journal of Vision*, *10*, 1–13. doi:10.1167/10.5.10

Van der Hallen, R., Evers, K., Brewaeys, K., Van den Noortgate, W., & Wagemans, J. (2015). Global processing takes time: A meta-analysis on local-global visual processing in ASD. *Psychological Bulletin*, *141*, 549–573. doi:10.1037/bul0000004

Wechsler, D. (1992). *Wechsler Intelligence Scale for Children* (3rd ed.). London, UK: The Psychological Corporation.

Weigelt, S., Koldewyn, K., & Kanwisher, N. (2012). Face identity recognition in autism spectrum disorders: A review of behavioral studies. *Neuroscience & Biobehavioral Reviews*, *36*, 1060–1084. doi:10.1016/j.neurbiorev.2011.12.2008

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, *81*, 141–145. doi:10.1037/h0027474

Young, A. W., Hellawell, D., & Hay, D. C. (1987). Configurational information in face perception. *Perception*, *16*, 747–759. doi:10.1068/p160747