

## PAPER

# Impairments in monkey and human face recognition in 2-year-old toddlers with Autism Spectrum Disorder and Developmental Delay

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### Abstract

*Face recognition impairments are well documented in older children with Autism Spectrum Disorders (ASD); however, the developmental course of the deficit is not clear. This study investigates the progressive specialization of face recognition skills in children with and without ASD. Experiment 1 examines human and monkey face recognition in 2-year-old children with ASD, matched for nonverbal mental age (NVMA) with developmentally delayed (DD) children, and typically developing children (TD), using the Visual Paired Comparison (VPC) paradigm. Results indicate that, consistent with the other-species effect, TD controls show enhanced recognition of human but not monkey faces; however, neither the ASD nor the DD group show evidence of face recognition regardless of the species. Experiment 2 examines the same question in a group of older 3- to 4-year-old developmentally disabled (ASD and DD) children as well as in typical controls. In this experiment, both human and monkey faces are recognized by all three groups. The results of Experiments 1 and 2 suggest that difficulties in face processing, as measured by the VPC paradigm, are common in toddlers with ASD as well as DD, but that these deficits tend to disappear by early preschool age. In addition, the experiments show that higher efficacy of incidental encoding and recognition of facial identity in a context of passive exposure is positively related to nonverbal cognitive skills and age, but not to overall social interaction skills or greater attention to faces exhibited in naturalistic contexts.*

### Introduction

Autism is an early-onset complex developmental disorder characterized by significant impairments in social reciprocal interaction, deficits in communication, and the presence of repetitive behaviors and restricted interests. Impairments in social development are pervasive and affect multiple areas including perception of facial identity, and the ability to recognize facial gestures such as affect and gaze. In the pre-linguistic period of development, faces provide an important route of communication and, and later on, continue to supplement verbal communication with unique social signals. While in autism the extent of the abnormalities in face processing do not typically lead to prosopagnosia, the affected school-age children, adolescents, and adults show impairments in face recognition skills (e.g. Boucher & Lewis, 1992; Joseph & Tanaka, 2003; Klin, Sparrow, de Bildt, Cicchetti, Cohen & Volkmar, 1999), and appear to employ a feature-based rather than a holistic strategy in

face processing (Joseph & Tanaka, 2003; Tanaka, Kiefer & Bukach, 2004; Teunisse & de Gelder, 2003). Moreover, when attending to both static and dynamic images of faces, individuals with autism spend less time monitoring the eye area as compared to typical controls (Dalton *et al.*, 2005; Joseph & Tanaka, 2003; Klin, Jones, Schultz, Volkmar & Cohen, 2002a, 2002b; Pelphrey, Sasson, Reznick, Paul, Goldman & Piven, 2002). In addition, compared to typical controls, individuals with autism show an unusual pattern of activation in the brain areas involved in face processing (Grelotti, Klin, Gauthier, Skudlarski, Cohen, Gore, Volkmar & Schultz, 2005; Pierce, Haist, Sedaghat & Courchesne, 2004; Pierce, Mueller, Ambrose, Allen & Courchesne, 2001; Schultz, Gauthier, Klin, Fulbright, Anderson, Volkmar, Skudlarski, Lacadie, Cohen & Gore, 2000). These perceptual peculiarities appear specific to faces, as recognition of objects is typically unaffected (Dalton *et al.*, 2005; Klin *et al.*, 1999; Tantam, Monaghan, Nicholson & Stirling, 1989). The impairments in face processing extend

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beyond facial identity and include deficits in identifying emotional expressions, gender, and gaze direction, as well as difficulties in lip reading (Baron-Cohen, Campbell, Karmiloff-Smith, Grant & Walker, 1995; de Gelder, Vroomen & Van der Heide, 1991; Deruelle, Rondan, Gepner & Tardif, 2004; Gepner, de Gelder & Scania, 1996).

While research on older children and adults contributes greatly to our understanding of the developmental endpoints of face perception in autism, the early developmental course of face processing abnormalities in autism is unknown. In typical development the emergence of face recognition skills reflects a prolonged and experience-dependent process extending from a generalized sensitivity to face-like configurations to a highly specialized and fine-tuned ability to recognize faces regardless of spatial orientation, emotions they express, or age (Nelson, 2001). Shortly after birth, infants exhibit sensitivity to face-like stimuli (Cassia, Simion & Umiltà, 2001; Turati & Simion, 2002) and show rudimentary face discrimination skills (Bartrip, Morton & De Schonen, 2001; Pascalis, de Schonen, Morton, Deruelle & Fabre-Grenet, 1995). By 3 months they begin to form elementary face prototypes (de Haan, Johnson, Maurer & Perrett, 2001) and by 5 to 7 months, they pay attention to invariant perceptual characteristics specific to gender (Leinbach & Fagot, 1993) and certain facial expressions (Bornstein & Arterberry, 2003; Kotsoni, de Haan & Johnson, 2001). One of the currently prevailing hypotheses suggests that in the first postnatal months the system involved in face perception is broad and sensitive to both human and non-human faces (Nelson, 2001). The system subsequently has the potential to become specialized for face recognition through exposure to the facial stimuli most prevalent in the child's natural environment. Some empirical evidence supporting the tuning or gradual specialization hypothesis comes from studies of recognition of same- and other-species faces in human infants. While 6-month-old infants are capable of discriminating between familiar and novel exemplars of both human and monkey faces, by 9 months they show evidence for recognition of human but not monkey faces (Pascalis, de Haan & Nelson, 2002). The transition between 6 and 9 months has been interpreted as evidence for experience-dependent cortical specialization or perceptual narrowing resulting from extensive exposure to human but not monkey faces and leading in to the 'other-species' effect reported in older children and adults (Pascalis *et al.*, 2002; Pascalis, Demont, de Haan & Campbell, 2001). This type of specialization might be analogous to the phenomenon observed in speech perception occurring between 6 and 10 months (Cheour, Ceponiene, Lehtokoski, Luuk, Allik, Alho & Näätänen, 1998; Kuhl, Williams, Lacerda, Stevens &

Lindholm, 1992), or the development of the non-native effect (or 'other-race' effect) (Sangrigoli & de Schonen, 2004a, 2004b; Tanaka *et al.*, 2004; Chance, Turner & Goldstein, 1982; Golby, Gabrieli, Chiao & Eberhardt, 2001).

While the direct evidence regarding development of children with autism in the first year of life is still very limited, analysis of video diaries collected in the first 6 months of life suggests that infants with autism orient to and look at others less frequently than their typically developing peers (Maestro, Muratori, Cavallaro, Pei, Stern, Golse & Palacio-Espasa, 2002). By 12 months children with autism spend significantly less time looking at people than their mentally retarded and typically developing counterparts (Osterling, Dawson & Munson, 2002). Limited attention to people, poor eye contact and gaze monitoring, limited sensitivity to others' facial expressions, and a tendency to focus preferentially on objects, constitute some of the core behavioral indices of autism in the second year (see Chawarska & Volkmar, 2005, for review). A very limited body of research on face perception at the early stages of ASD suggests that some abnormalities might be detectable in toddlers and preschoolers. In a study of attention cuing by biological (eyes) and nonbiological (object) motion, Chawarska, Klin and Volkmar (2003) demonstrated that while 2-year-olds with ASD responded to gaze and non-biological motion cues in a similar manner as typical controls, their response time was not affected by the facial character of the stimuli. Toddlers were required to attend to an image of a face or an object and then shift their gaze quickly to a peripheral stimulus. Typical toddlers had significantly longer reaction time to targets that were preceded by faces as compared to objects, suggesting that their ability to disengage and shift attention was encumbered by the facial (social) character of the cue. Toddlers with ASD, however, responded to the peripheral targets very quickly and did not show the same face-specific attentional phenomenon as their typical counterparts. While indirect, these findings suggest that, by 2 years of age, faces might recruit a different attentional and/or processing mechanism in ASD.

Furthermore, Dawson and colleagues (Dawson, Carver, Meltzoff, Panagiotides, McPartland & Webb, 2002) reported abnormalities in face processing in 3- to 4-year-old children with ASD using the event-related brain potentials (ERP) paradigm. The ERPs were recorded during passive viewing of familiar and unfamiliar faces and toys. Children without autism (typical and developmental delays groups) showed a differential response to familiar faces and familiar toys as compared to unfamiliar ones. Children with autism, however, showed a differential response only to familiar and unfamiliar toys suggesting that, by the age of 3 to

4 years, they exhibit specific abnormalities in patterns of brain activity in response to faces.

Several hypotheses have been advanced regarding the roots of the face processing abnormalities in autism (Dawson, Meltzoff, Osterling, Rinaldi & Brown, 1998; Dawson, Webb & McPartland, 2005; Klin, Jones, Schultz & Volkmar, 2003; Schultz, 2005). One approach posits the presence of primary perceptual or cognitive deficits that might impair selective processing of facial stimuli. These deficits might be driven by some neurophysiological abnormalities, such as dysfunction in the brain circuitry involved in processing of facial or social stimuli, and lead to impairments in the perception of not only facial features, but also social interactions. The second approach is built around the social-motivational hypothesis suggesting that face processing deficits in autism are secondary to deficits of diminished salience of social stimuli and/or the paucity of motivation to engage in reciprocal social interactions with others (Dawson, Carver *et al.*, 2002; Grelotti, Gauthier & Schultz, 2002; Klin *et al.*, 2003; Schultz, 2005). According to this approach, limited social motivation leads to reduced attention to social stimuli including faces, facial gestures, and expressions, and results in secondary impairments in the processing of these stimuli.

Lack of prospective experimental studies on early face recognition development in children with ASD does not currently allow for determination of whether infants with ASD lack the initial perceptual skills that prepare typical newborns to detect and attend to face-like stimuli in the environment or whether their development might be disrupted by autism-specific pathogenic motivational factors. Regardless of the source of difficulty, the outcome might lead to limited experiences with faces and facial gestures and result in a disruption of the early experience-dependent developmental processes. It has to be noted, however, that currently there is little evidence regarding the timing of the critical periods, their duration, and the minimal amount of exposure sufficient and necessary for the typical face processing system to emerge (Nelson, 2001).

Identifying the course of face perception development in autism and comparing it to that observed in developmentally delayed and typical peers would greatly advance our understanding of the origins of the abnormalities in this area and the impact of early experience on the development of this highly consequential skill for social functioning. The importance of studying face recognition in very young children with ASD extends beyond the interest in their ability to differentiate between people and remember facial identities, as the neural structures involved in face processing including the fusiform gyrus, superior temporal sulcus, and amygdale, are also involved in social cognition in general (see Schultz, 2005, for review).

The goal of this study is to examine face recognition skills in typically developing (TD) 2-year-old toddlers as well as matched for nonverbal mental age toddlers with Autism Spectrum Disorders (ASD) and developmental delay (DD). The Visual Paired Comparison (Fantz, 1964) paradigm is employed to compare the recognition of two types of stimuli differing in the level of baseline familiarity for toddlers developing in the North East of the US: human faces (HF) and monkey faces (MF). The VPC paradigm targets an incidental learning process resulting from passive exposure to a stimulus during a familiarization period. The familiarization period is typically followed by a recognition phase during which the familiar stimulus is paired with a novel one. Durations of visual fixations on novel and familiar stimulus act as key measures of recognition memory. The paradigm relies on preference for novelty; thus, longer fixation on the novel stimulus signifies that the familiar stimulus has been encoded and recognized (Kaplan, Werner & Rudy, 1990; Pascalis & de Haan, 2003). The paradigm is particularly suitable for use with subjects drawn from a wide range of ages and abilities, especially nonverbal individuals or those who might have difficulties in understanding or following verbal instructions (e.g. infants).

We hypothesized that TD and DD controls would respond differentially to the two types of facial stimuli and, consistent with 'the other-species effect', would show novelty preference in the HF but not the MF conditions. Furthermore, we hypothesized that if the pathogenic factors specific to ASD disrupt development of face recognition at very early stages of development we might observe a lack of face recognition regardless of species. Alternatively, should the limited salience of social stimuli result in the disruption of the perceptual specialization observed in typical children, we might observe recognition of both types of facial stimuli, and thus, a lack of 'the other-species effect'.

## Experiment 1

### *Method*

#### Participants

The participants were recruited from a clinic specializing in early ASD diagnosis or from a cohort participating in a longitudinal study of social-cognitive development. The best estimate clinical diagnosis was assigned by a team of highly experienced practitioners consisting of a clinical psychologist, psychiatrist, and speech and language pathologist and was based on a review of medical and developmental history (Autism Diagnostic Interview-

Revised; Rutter, Le Couter & Lord, 2003), diagnostic and developmental test results (Autism Diagnostic Observation Schedule-Generic; Lord, Risi, Lambrecht, Cook, Leventhal, DiLavore, Pickles & Rutter, 2000, Mullen Scales of Early Learning; Mullen, 1995), and direct clinical observation. The diagnosis of ASD was based on the DSM-IV criteria modified for children under the age of 3 (see Chawarska & Volkmar, 2005, for review) with emphasis on the absence or significant delay of early emerging dyadic and triadic interaction skills, limited nonverbal communication skills, and with a lesser emphasis on the presence of stereotypic behaviors. Data from longitudinal studies indicate that clinical diagnosis of ASD in the second and third year of life is stable, especially if delivered by expert clinicians (Barton, Cherkasov, Hefter, Cox, O'Connor & Manoach, 2004; Chawarska, Klin, Paul & Volkmar, in press; Cox, Klein, Charman, Baird, Baron-Cohen, Swettenham, Drew & Wheelwright, 1999; Eaves & Ho, 2004; Lord, 1995; Stone, Lee, Ashford, Brissie, Hepburn, Coonrod & Weiss, 1999). Children in the developmental delay group underwent an identical assessment as the ASD group and based on the results, they received a clinical diagnosis of global developmental delay or specific language impairment.

Fifty children between the ages of 14 and 35 months were enrolled into the study. In 10 children (three ASD, five DD, and two TD) testing was not completed due to lack of cooperation ( $N = 6$ ) or for technical reasons ( $N = 4$ ). Forty children completed at least one of the procedures. Data from nine (six in the HR and three in the MF condition) sessions had to be excluded from the analysis due to recording problems ( $N = 5$ ) or attentional reasons (i.e. child failed to attend during the test phase) ( $N = 4$ ). Thus, the final sample included 14 toddlers with ASD who contributed 12 HF and 13 MF sessions, 16 toddlers with developmental delays (DD) who contributed 13 HF and 14 MF sessions, and 10 typical controls (TC) who contributed nine HF and 10 PF (see Table 1 for sample characteristics).

Developmental skills were assessed with the Mullen Scales of Early Learning (Mullen, 1995). The Mullen scales provide standard T scores and age equivalent scores in verbal and nonverbal domains. Social and communicative functioning was documented using a standardized diagnostic observation session, the ADOS. The ADOS quantifies deficits in the areas of Communication (ADOS-C), Social Reciprocal Interaction (ADOS-SRI), Play (ADOS-P), and Stereotyped Behaviors and Restricted Interests (ADOS-SB) (Lord *et al.*, 2000). In addition, based on selected ADOS items concentrating specifically on presence of eye contact and attention to faces, we computed the eye contact (EC) Index by summing each child's scores on the following items: Pointing (A7),

Unusual Eye Contact (B1), Integration of Gaze (B4), Response to Name (B6), Requesting (B7), Showing (B9), Spontaneous Initiation of Joint Attention (B10), and Response to Joint Attention (B11). The scoring of these items is based on the child's ability to look at the face of the examiner and make eye contact contingently within a context of communicative and interactive bids. Low score (0) indicates presence of eye contact either alone or integrated with other actions (e.g. making requests, responding to name), with higher scores corresponding to either inconsistent or lack of eye contact. This measure provides a proxy for attention to eyes and faces in a context of naturalistic interaction and play. Adaptive levels of functioning in the areas of Socialization, Communication, Daily Living, and Motor skills were assessed with the Vineland Adaptive Behaviors Schedule-Expanded (Sparrow, Balla & Cicchetti, 1984).

Sample characteristics were analyzed with a series of between-group ANOVAs with the Tukey Studentized Range post-hoc test, whenever applicable. The three groups were matched on nonverbal mental age (NVMA) defined as an average of the Mullen Visual Reception and Fine Motor scales age equivalent scores,  $F(2, 36) = 1.87$ ,  $p > .05$ . Matching based on nonverbal level of functioning resulted in significant differences in the chronological age at the time of testing,  $F(2, 39) = 6.08$ ,  $p < .02$ ; while there was no significant difference between ASD and DD group, TD controls were younger than the ASD group. Children in the DD group had significantly lower scores than those in the ASD groups in all ADOS-G domains as well as the EC Index (see Table 1).

#### Materials and apparatus

The stimuli consisted of two sets of color images of human and monkey faces (see Figures 1 and 2). Each set consisted of two faces. The monkey faces were obtained courtesy of Dr Olivier Pascalis; the human faces were selected from the MacBrain Face Stimulus Set.<sup>1</sup> Using the software Adobe Photoshop, the images were cropped to exclude the ears and information about the contour of the head and were equated in color and luminosity. The familiarization face was approximately  $11 \times 15$  cm viewed from a distance of 75 cm.

The display apparatus consisted of a computer monitor, two speakers, and a camera mounted behind a black screen, so that only the front of the monitor screen was visible

<sup>1</sup> Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham at [tott0006@tc.umn.edu](mailto:tott0006@tc.umn.edu) for more information concerning the stimulus set.

**Table 1** *Experiment 1: Sample characteristics*

Sample characteristic	Typical control <i>N</i> = 10	Developmental delay <i>N</i> = 16	Autism Spectrum Disorder <i>N</i> = 14
Chronological age (mo)			
Mean (SD)	19.7 (4.7)	23.7 (6.7)	27.9 (4.9)*
Range	14–29	14–33	17–35
Nonverbal MA (mo)			
Mean (SD)	19.6 (3.9)	17.3 (4.6)	19.9 (2.9)
Range	14–24	10–24	14–24
% Male	80	75	71
ADOS communication			
Mean (SD)	–	2.9 (2.3)	4.92 (1.4)**
ADOS social interaction			
Mean (SD)	–	5.7 (5.0)	11.8 (1.9)**
ADOS play and imagination			
Mean (SD)	–	2.9 (1.1)	3.6 (.63)*
ADOS stereotyped behaviors			
Mean (SD)	–	1.7 (1.7)	4.1 (1.7)**
Vineland Socialization			
Mean (SD)	–	78 (10.9)	66 (10.7)**
EC index			
Mean (SD)	–	6.8 (5.7)	13.2 (2)**

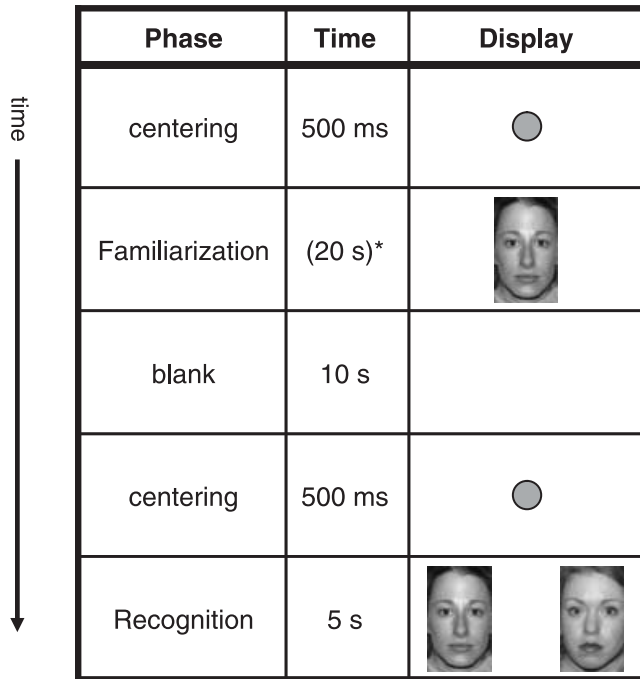
\*  $p < .05$ ; \*\*  $p < .01$ .

to the child. The infant's eye level was aligned with the center of the monitor. Two speakers connected with the computer were located on the left and right side of the monitor and behind the screen. Four infrared light sources were positioned 10 inches from the corners of the monitor and provided illumination for an IR-sensitive camera (spectral sensitivity of 400 to 1300 nm) located directly above the screen. A 48-mm lens allowed acceptable resolution of the eyes and much of the subject's face at a distance of 75 cm. The video signal from the camera and the computer was displayed on one monitor positioned behind the child and the image was video recorded for off-line coding with a stopwatch running at increments of 15 ms. The video recording contained an image of the child's eyes and an insert screen with a view of the computer monitor to allow for coding of the child's eye movement as well as the timing and location of each stimulus presentation.

#### Procedure

The VPC procedure consisted of Familiarization and Recognition phases. We employed a fixed-level approach in which, during Familiarization phase, the stimulus was presented until each participant accumulated 20 s of fixation time. While novelty preference in 24-month-old infants has been reported following a 10-s familiarization period, we extended the period to 20 s to ensure that children with developmental disabilities would have an adequate opportunity for encoding the stimulus identity. Toddlers were placed in a car seat in front of a 27 × 36 cm

computer screen embedded in a black panel. An examiner positioned behind the child observed an image of the child's face on a TV monitor and controlled the stimuli presentation using a MacIntosh computer. After the child was placed in the chair, the lights in the room were extinguished and the Familiarization Phase began. The appearance of the familiarization stimulus was preceded by a blinking circle located at the center of the screen accompanied by a sound played from the speakers to attract the child's attention to the screen. The centering stimulus was followed immediately by a presentation of the familiarization stimulus (i.e. a human or monkey face). Once the child fixated on the stimulus, the examiner pressed an arrow key on a keyboard. When the child looked away, the examiner released the key. This process was repeated for subsequent re-fixations of the stimulus by the child. The computer program recorded the duration of individual fixations and once the cumulative fixation time reached 20 seconds, the familiarization phase was terminated and the stimulus was extinguished. No centering stimulus was used if the child looked away from the familiarization stimulus and thus, the child was free to regulate his or her attention during the phase. After a 10-second delay, a cue appeared in the center of the screen for 500 ms, and this was followed by the Recognition Phase. The Recognition Phase consisted of a 5-second presentation of the familiar stimulus paired with a novel one. The single test trial represented a visual analog of the 'forced choice' response paradigm used frequently in studies of older children and adults. This design contrasted with that typically adopted for young infants, where two test

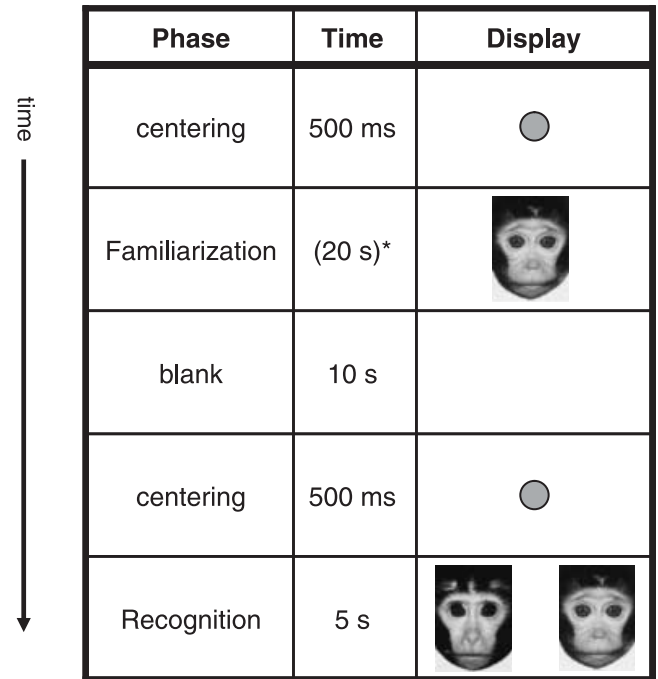


**Figure 1** Human Face Recognition: One trial of the Visual Paired Comparison Procedure. The column labeled 'display' shows the stimulus display presented to subjects as the trial proceeds. The experiment begins with a centering stimulus that draws the subject's attention to the center of the screen. This is followed the Familiarization phase where a particular face is displayed for 20 seconds of accumulated time (see text). Familiarization phase is followed by 10-s delay during which the screen is blank. This is followed by another centering stimulus (5 s) and a 5-s Recognition phase where two faces are presented simultaneously on either side of the screen. One of these faces is identical to the face shown in the Familiarization phase. The other face is a novel face that is matched to the familiar face in terms of a number of elementary image qualities (overall luminance, shape, size, etc.).

trials are often used with novel and familiar face counterbalanced with regard to the location. Considering older age and presumably faster speed of processing of the subjects, there was a concern that the results of the second test trial might be confounded by familiarization that might have occurred during first the 5-second test trial. The location of the novel stimulus was counterbalanced (left or right side) across subjects. Recognition of primate faces was tested first, followed by the testing of human face recognition on the second day of the assessment. The order was the same for all participants.

#### Dependent measures and data reduction

The dependent variables were the direction and duration of visual fixation on the face stimuli in Familiarization



**Figure 2** Monkey Face Recognition: One trial of the Visual Paired Comparison Procedure. This procedure is similar to the Human Face Recognition procedure, with the only difference being that human faces are exchanged with monkey faces.

and Recognition phases. All experimental sessions were coded off-line for location and duration of visual fixations by two experienced coders using the software Observer 5.0. The coding results were subsequently compared and all sessions with identified discrepancies re-coded by consensus. The duration of visual fixations analysis presented in this paper is based on the average across two coders. The timing disparity between the coders ranged from 0 ms to 400 ms ( $M = 23$  ms,  $SD = 90$  ms).

#### Results

##### Familiarization phase

There were no significant differences between groups and conditions in either the total time required to accumulate the predetermined 20 seconds of exposure to the familiarization stimulus or the number of times a subject looked at the stimuli to meet the 20-s criterion (see Table 2).

##### Recognition phase

We examined the distribution of the fixations to novel and familiar stimuli in each group and condition. Two outliers (1 DD and 1 TD) were identified in the MF

**Table 2** Experiment 1: Mean (SD) duration of the Familiarization phase in Experiments 1 and 2 and number of looks to the 20-s criterion

Familiarization phase	Stimulus		ASD	DD	TC
Experiment 1	HF	Duration	30.4 (8.8)	28.9 (8.5)	31.7 (11.8)
		# Looks	7.3 (3.7)	5.2 (2.9)	5.4 (3.4)
	MF	Duration	26.1 (5.7)	36.5 (23.5)	31.4 (19.1)
		# Looks	4.9 (2.7)	5.6 (3.5)	5.3 (5.8)
Experiment 2	HF	Duration	28.0 (6.9)	29.5 (6.4)	26.5 (7.6)
		# Looks	6.3 (2.9)	5.6 (3.4)	3.0 (2.1)*
	MF	Duration	29.7 (5.7)	31.2 (9.5)	28.1 (7.9)
		# Looks	6.3 (2.6)	7.6 (4.3)	4.4 (1.8)*

**Table 3** Experiments 1 and 2: Novelty preference ratio in ASD, DD and NC groups

Stimulus	Diagnosis	Experiment 1		Experiment 2	
		NovPref ratio	<i>p</i> value	NovPref ratio	<i>p</i> value
Human	ASD	.51 (.13)	.72	.61 (.09)	.002
	DD	.51 (.15)	.85	.62 (.12)	.05
	TD	.62 (.08)	.002	.58 (.07)	.002
Monkey	ASD	.52 (.13)	.47	.65 (.09)	.001
	DD	.54 (.13)	.22	.62 (.07)	.001
	TD	.54 (.11)	.27	.60 (.10)	.001

condition and excluded from the analysis, as the toddlers fixated exclusively on the left stimulus. After these two exclusions, the minimum total fixation duration on the left or right test stimulus was 800 ms. To rule out the between-group differences in fixation time during the Recognition phase we examined the duration of fixation on test stimuli in both conditions. No group or condition effects were found. Out of a possible 5 s, the ASD group spent on average 4.28 s (SD = .67) fixating HF and 4.41 s (SD = .59) fixating MF stimuli. In the DD group the averages were 4.55 s (SD = .47) and 4.40 s (SD = .68) in the HF and MF conditions, respectively. In the TD group, the means were 4.13 s (SD = .96) in HF and 4.02 s (SD = 1.2) for MF conditions.

Face recognition was examined by comparing fixation duration of familiar and novel stimuli as well as comparing the Novelty Preference ratio (NovPref) (Novel stimulus fixation duration/Total fixation duration) to the chance level (50%) (see Table 3). A within-subject ANOVA on fixation duration in the TD group indicated a significant effect of direction of fixation (novel/familiar),  $F(1, 17) = 15.69$ ,  $p < .001$ , and no stimulus or stimulus  $\times$  direction interaction, such that in both conditions children tended to look longer on the novel stimulus. However, the novelty preference ratio exceeded chance level only in the HF,  $t(8) = 4.71$ ,  $p < .002$ , but not in the MF condition. In the ASD group, an ANOVA comparing fixation duration to novel and familiar stimulus in both conditions did not

yield any significant effects. Similarly, the Novelty Ratio indices were not significantly different from chance level. A similar pattern of results was found in the DD group: there was no significant effect of stimulus or direction of gaze on fixation time, and the Novelty Preference ratios were at the chance level.

### Discussion

Results of Experiment 1 indicate that typically developing infants in the second year of life process and recognize human faces more readily than primate faces. This finding is consistent with the other-species effect (Pascalis *et al.*, 2002) and would suggest that the pattern previously reported in 9-month-old babies still prevails in the second year of life. However, despite a long familiarization time and adequate attention to the test stimuli, infants with ASD and DD did not show evidence for recognition of human or monkey faces. This pattern of results suggests that difficulties in rapid processing and recognition of facial stimuli might not be specific to toddlers with ASD, as toddlers with other developmental delays matched for chronological and nonverbal mental age showed an identical performance pattern on both tasks.

Considering documented ASD-specific abnormalities in face processing in older individuals including preschool-age children, we were interested in whether in older toddlers

face recognition abnormalities as measured by the VPC paradigm become syndrome-specific.

## Experiment 2

Experiment 2 examined face recognition skills in 3- to 4-year-old typical, ASD, and DD children. The purpose of this experiment was twofold. First, we wished to examine the other-species effect in 3- to 4-year-old typical children. Previous reports suggested that by the age of 5 years, typically developing children can recognize both monkey and human faces, though the accuracy was greater for more familiar human faces (Pascalis *et al.*, 2001). The same preschoolers, however, were not able to recognize faces that are further removed from the human and monkey face prototype, such as sheep faces. Notably, the developmental trajectory of the other-species effect between 9 months and 5 years is largely unknown. Second, we wished to examine changes in face recognition that might occur at this age in the developmentally disabled groups. Specifically, should the impairments in performance on face recognition task be non-specific early on, these deficits might become syndrome-specific with age when the developmental trajectories of children with ASD and those with non-autistic disorders progressively diverge. A similar pattern was reported in studies of executive function deficits in ASD, where earlier non-specific deficits later differentiated (Dawson,

Meltzoff, Osterling & Rinaldi, 1998; Dawson, Munson *et al.*, 2002; Griffith, Pennington, Wehner & Rogers, 1999).

## Method

### Participants

Participants were recruited via the same route and underwent an identical characterization process as in Experiment 1. The initial sample consisted of 47 participants tested in two conditions. Nine subjects (five ASD and four DD) could not be tested at all due to technical reasons ( $N = 2$ ) or lack of cooperation ( $N = 7$ ). In the remaining 38 children, data from four HF and three MF sessions had to be excluded due to technical and attentional reasons. Following these *a priori* exclusions, the sample consisted of 15 children with ASD (14 HF and 12 MF), 10 with DD (eight HF and 10 MF), and 13 TD cases (12 HF and 13 MF) (see Table 4 for sample characteristics). Preschoolers with ASD were slightly, but not significantly, older than DD and TD controls,  $F(2, 36) = 2.84, p < .072$ . There were no significant differences in the nonverbal age levels,  $F(2, 32) = 2.35, p > .05$ . Preschoolers with ASD had significantly higher scores on the ADOS-G domains than the DD controls in all domains except for Play and Imagination. The EC Index was significantly elevated in the ASD as compared to the DD group.

**Table 4** Experiment 2: Sample characteristics

Sample characteristic	Typical control $N = 13$	Developmental delay $N = 10$	Autism Spectrum Disorder $N = 15$
Chronological age (mo)			
Mean (SD)	38.0 (8.2)	39.5 (6.7)	45.9 (6.7)
Range	36–50	36–59	36–53
Nonverbal MA (mo)			
Mean (SD)	37.7 (7.7)	33.0 (9.6)	42.1 (10.8)
Range	36–50	20–50	25–58
% Male	53	80	92
ADOS communication <sup>1</sup>			
Mean (SD)	–	1.1 (1.1)	4.0 (1.8)***
ADOS social interaction <sup>2</sup>			
Mean (SD)	–	3.8 (2.3)	7.7 (2.7)**
ADOS play and imagination			
Mean (SD)	–	1.4 (1.5)	2.15 (1.5)
ADOS stereotyped behaviors			
Mean (SD)	–	.90 (.9)	3.2 (1.8)**
Vineland Socialization			
Mean (SD)	–	81 (9.9)	74 (8.7)
EC index			
Mean (SD)	–	3.2 (3.0)	8.7 (3.3)**

<sup>1</sup> Cut-off point for Autism = 4, ASD = 2.

<sup>2</sup> Cut-off point for Autism = 7, ASD = 4.

\*  $p < .05$ ; \*\*  $p < .01$ ; \*\*\*  $p < .001$ .

### Materials and apparatus

Materials and apparatus were identical to those used in Experiment 1.

### Procedure

The procedure was identical to the procedure in Experiment 1.

### Dependent variables and data reduction

Dependent variables were identical to Experiment 1. The average of two coders was used and the Novelty Preference ratio was computed for all participants for each condition.

### Results and discussion

#### Familiarization phase

A mixed model ANOVA indicated no significant effects of group or stimulus on the time necessary to accumulate the prerequisite 20 s of fixation time on the habituation stimulus (see Table 2). However, unlike in Experiment 1, there was a significant between-group difference regarding the number of looks to criterion,  $F(2, 63) = 7.08, p < .002$ . Post-hoc comparisons with Tukey correction for multiple tests indicated that the TD group looked away from the familiarization stimuli less often as compared to the DD,  $t(63) = 3.24, p < .01$ , and ASD,  $t(63) = 3.19, p < .01$ . Neither the effects of stimulus nor stimulus  $\times$  group interactions were significant.

#### Recognition phase

As in Experiment 1, we examined the distribution of fixations to novel and familiar stimuli in each group and condition for outliers. One outlier was identified in the TD group with a fixation bias to one side. There were no differences between groups and conditions in the total fixation time during the Recognition phase. Out of a maximum 5 s the ASD group spent on average 4.54 s ( $SD = .76$ ) fixating HF and 4.39 s ( $SD = .81$ ) fixating the MF stimuli. In the DD group the averages were 3.97 s ( $SD = 1.49$ ) and 4.66 s ( $SD = .32$ ) in the HF and MF conditions, respectively. In the TD group, the means were 4.70 s ( $SD = .52$ ) in the HF and 4.60 s ( $SD = .54$ ) for MF conditions. A series of within-subject ANOVAs for each group indicated that preschoolers tended to look significantly longer at the novel stimulus regardless of condition and group (ASD group:  $F(1, 24) = 45.22, p < .001$ ; DD:  $F(1, 16) = 22.47, p < .001$ ; and TD:  $F(1, 23)$

$= 16.59, p < .001$ ). There were no significant effects of condition or condition  $\times$  type of stimuli interactions in either group. In all groups both in the HF and MF conditions the novelty preference ratio was significantly above chance level (see Table 3).

### Comparison of performance in the developmentally disabled groups in Experiments 1 and 2

Several factors including age, cognitive functioning level, or social functioning level might have contributed to the apparently better recognition performance in the ASD and DD groups at the age of 3 to 4 years as compared to 2 years. A series of ANOVAs comparing the ASD and DD groups in Experiments 1 and 2 suggested that children in Experiment 2 were not only older (by definition), but also had a higher nonverbal mental age,  $F(1, 43) = 57.07, p < .001$ , lower EC indices,  $F(1, 42) = 10.20, p < .01$ , and lower ADOS SRI scores,  $F(1, 42) = 8.87, p < .01$ . The difference in the Vineland Socialization score was marginally significant,  $F(1, 43) = 3.44, p < .07$ .

To explore which of the factors might have contributed to the performance on the face recognition tasks, a stepwise regression analysis with the novelty preference ratio as a dependent variable and the ADOS-G Social Reciprocal Interaction (SRI) scores, EC Index, Vineland Socialization standard score, nonverbal developmental quotient (DQ) score ( $[\text{nonverbal mental age}/\text{chronological age}] \times 100$ ), chronological age (CA), diagnostic status, and type of stimulus as independent variables was conducted on the two samples combined. Only two predictors of importance were found: CA ( $B = .003, SE = .001, F = 8.17, p < .01$ ), and nonverbal DQ ( $B = .002, SE = .0001, F = 7.91, p < .001$ ), jointly explaining approximately 14% of variance ( $R^2 = .141$ ). Diagnosis, type of stimulus, measures of social adaptive skills (Vineland Socialization score), autistic social disturbance (ADOS SRI scores), and specific attention to faces and eyes were not associated with the novelty preference ratio. Higher CA and nonverbal DQ were associated with greater novelty preference ratio.

### General discussion

The results of Experiments 1 and 2 extend previous reports on the development of face recognition in typical children and begin to fill the gap in our understanding of the development of this skill between late infancy and preschool age. As found in 9-month-old babies, children in the second year of life recognize human faces

more readily than monkey faces, suggesting persistence of the other-species effect during this developmental period.

In comparison with the matched for nonverbal cognitive levels TD controls, impairments in incidental learning and face recognition were present in toddlers with a range of developmental disabilities, including ASD and various developmental delays. To the best of our knowledge this is the first study targeting visual recognition skills in very young children with developmental disabilities; hence, many questions remain to be clarified. Specifically, there is a pressing need to elucidate the role of attentional, learning, and memory factors on their performance on the VPC paradigm. Considering that attentional difficulties in toddlers with disabilities are often reported, there was a concern that attention regulation might impact performance of toddlers with ASD and DD. However, these toddlers did not differ from their TD peers in the amount of time spent fixating on facial stimuli or the time necessary to reach the familiarization criterion. Interestingly, in the absence of distractors, toddlers with ASD had no difficulties in engaging and maintaining attention on the facial stimuli. This finding is in stark contrast with their behavior during the diagnostic assessment session where they consistently showed limited attention to faces in situations calling for eye contact while either initiating an interaction (e.g. making a request) or responding to social bids. Thus, it might be that faces *per se* do not have a disorganizing or aversive effect on ASD toddlers, and limited attention to faces is related to a broader context in which faces are usually encountered: complex and dynamic social interaction. This finding is consistent with reports regarding face processing in older, higher functioning individuals. In the context of passive exposure to pictures of faces and movies depicting complex social situations, individuals with autism spent a similar amount of time looking at faces as typical controls (albeit showing a different face scanning pattern) (Dalton *et al.*, 2005; Klin *et al.*, 2002b). The nature of this dissociation between behavior during implicit and perceptual tasks, such as the VPC paradigm, and those prevalent in the naturalistic social environment awaits further clarification. At the same time, the DD toddlers were more attentive to faces and made eye contact more frequently during a naturalistic interaction with an adult, and yet did not show clear evidence for face recognition in the VPC task.

While the attentional factors might not have necessarily been at play, factors related to learning and memory might need to be considered. In selecting parameters for Experiments 1 and 2 we were guided by research on typical infants, as data on VPC performance in disabled children are lacking. Novelty preference has been

demonstrated in 12-, 18-, and 24-month-old typically developing children in the object recognition VPC task with a familiarization time of only 10 s (Robinson & Pascalis, 2004) and infants as young as 3 months have shown recognition memory after a 2-min delay (Pascalis, de Haan, Nelson & de Schonen, 1998). We extended familiarization time to 20 s assuming that this time would be sufficient for encoding in developmentally disabled groups, and employed a 10-s delay that placed limited demand on visual recognition memory. Further, in Experiment 1 there were no differences between the groups in terms of the number of fixations during the familiarization phase, which provides an additional support to the observation that difficulties in learning are unlikely to account for the observed between-group differences.

There are, however, other factors that need to be considered. Failure to recognize faces might be a result of the 'outer-feature' bias in face processing often observed in infants and young children. Young infants are less likely to scan inner facial features (Maurer & Salapatek, 1976) and, until the second month, infants are unable to recognize their mother's face based on the internal feature of the face alone (Bartrip *et al.*, 2001). The accuracy of face recognition continues to be enhanced by the presence of the outer features well into early school years both for familiar and unfamiliar faces (Campbell & Tuck, 1995; Campbell, Walker & Baron-Cohen, 1995; Want, Pascalis, Coleman & Blades, 2003). Stimuli employed in this study contained very limited information regarding head contour, hair, and ears, forcing the participants to rely on the inner features instead. While this manipulation did not interfere with performance of TD subjects, it might have challenged face processing skills in developmentally disabled children.

Finally, while lack of novelty preference in both groups might reflect the same underlying mechanism, it is plausible that their performance shared only surface characteristics. The time spent examining the stimuli was the same in all groups, but it is not clear if the scanning strategies employed by toddlers with and without ASD were equivalent. Several reports suggest that during scanning of static images of human faces older individuals with autism spend less time looking at the eyes as compared to typical controls (Dalton *et al.*, 2005; Pelphrey *et al.*, 2002). Shorter fixation of the eye area in autism might lead to limited access to information consequential for encoding facial identity and impede performance on the VPC task, especially under time constraints. One might speculate that performance of the ASD toddlers might have been impeded by their ineffective scanning pattern, but those with developmental delay might have been hindered by limited memory or

slow processing speed. The aforementioned factors related to learning, memory, context, and processing strategies will have to be addressed in future studies.

Performance of the typical 3- to 4-year-olds suggests recognition of both human and monkey faces, a finding inconsistent with the other-species effect. This pattern sets them apart from young infants (Pascalis *et al.*, 2002), toddlers (Experiment 1), and adults (Pascalis *et al.*, 2002) and highlights limitations in our understanding of the ongoing specialization in the face processing system in early childhood and preschool age. It is likely that the system undergoes several tuning periods before it reaches its mature state. Studies of the non-native as well as inversion effects provide evidence in support of this hypothesis. While 3-month-old babies show better processing of faces belonging to a familiar morphological category (i.e. better recognition of Caucasian than Asiatic faces in Caucasian babies) suggesting that some tuning to the native morphology might be occurring very early on (Sangrigoli & de Schonen, 2004b), the other-race effect is modifiable by novel experience occurring after 3 years of age (Sangrigoli, Pallier, Argenti, Ventureyra & de Schonen, 2005). Similarly, exposing infants between 6 and 9 months to monkey faces can diminish the other-species effect observed typically at 9 months (Pascalis, Scott, Kelly, Shannon, Nicholson, Coleman & Nelson, 2005). Alternatively, the long familiarization time employed in this study might have facilitated perceptual encoding and recognition of monkey faces in this age-group, as it would for any other complex stimulus. Thus, replication of this study with a shorter familiarization time might help further elucidate the developmental trajectory of the other-species effect.

By the age of 3 to 4 years both groups with disabilities performed as well as their typically developing peers. This finding suggests that, when exposed passively to images of faces, preschoolers with ASD are capable of incidental learning leading to successful face discrimination and recognition. In order to understand the boundaries of this competency, it will be important to examine the process that leads to the successful performance with special focus on visual scanning strategies and the role of visual exposure and memory load in the processing of both facial and non-facial complex stimuli. Clarifying these issues will be particularly important in light of recent reports suggesting that individuals with ASD and control subjects process faces in a different manner (Chawarska *et al.*, 2003; Dawson, Carver *et al.*, 2002).

The results of Experiments 1 and 2 suggest that difficulties in face processing as measured in the VPC paradigm are common in toddlers with ASD as well as those with DD, but they tend to become less apparent by early preschool age. Higher efficacy of incidental

encoding and recognition of facial identity in a context of passive exposure was positively related to nonverbal level of functioning and chronological age but not to the overall social interaction skills or greater attention to faces exhibited in naturalistic contexts. The role of nonverbal cognitive functioning was most likely related to speed of processing and recognition memory. The independent contribution of chronological age is likely to reflect an interaction between the development of the neural system supporting face processing system and experience. Taken together, these results highlight the complexity of the development of face recognition skills in young children with developmental disabilities and lay a foundation for further studies of the early stages of ASD.

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## References

- Baron-Cohen, S., Campbell, R., Karmiloff-Smith, A., Grant, J., & Walker, J. (1995). Are children with autism blind to the mentalistic significance of the eyes? *British Journal of Developmental Psychology*, **13** (4), 379–398.
- Barton, J., Cherkasov, M., Hefter, R., Cox, T.A., O'Connor, M., & Manoch, D.S. (2004). Are patients with social developmental disorders prosopagnosic? Perceptual heterogeneity in the Asperger and socio-emotional processing disorders. *Brain*, **127** (8), 1706–1716.
- Bartrip, J., Morton, J., & De Schonen, S. (2001). Responses to mother's face in 3-week to 5-month-old infants. *British Journal of Developmental Psychology*, **19** (2), 219–232.
- Bornstein, M.H., & Arterberry, M.E. (2003). Recognition, discrimination and categorization of smiling by 5-month-old infants. *Developmental Science*, **6** (5), 585–599.
- Boucher, J., & Lewis, V. (1992). Unfamiliar face recognition in relatively able autistic children. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, **33** (5), 843–859.
- Boucher, J., Lewis, V., & Collis, G. (1998). Familiar face and voice matching and recognition in children with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, **39** (2), 171–181.
- Campbell, R., & Tuck, M. (1995). Recognition of parts of famous-face photographs by children: an experimental note. *Perception*, **24** (4), 451–456.
- Campbell, R., Walker, J., & Baron-Cohen, S. (1995). The development of differential use of inner and outer face

- features in familiar face identification. *Journal of Experimental Child Psychology*, **59** (2), 196–210.
- Cassia, V.M., Simion, F., & Umiltà, C. (2001). Face preference at birth: the role of an orienting mechanism. *Developmental Science*, **4** (1), 101–108.
- Chance, J., Turner, A., & Goldstein, A. (1982). Development of differential recognition for own- and other-race bias in face recognition. *The Quarterly Journal of Experimental Psychology*, **48A**, 879–894.
- Chawarska, K., Klin, A., Paul, R., & Volkmar, F.R. (in press). Autism Spectrum Disorder in the second year: stability and change in syndrome expression. *Journal of Child Psychology and Psychiatry*.
- Chawarska, K., Klin, A., & Volkmar, F. (2003). Automatic attention cueing through eye movement in 2-year-old children with autism. *Child Development*, **74** (4), 1108–1122.
- Chawarska, K., & Volkmar, F. (2005). Autism in infants and toddlers. In F. Volkmar, A. Klin, & R. Paul (Eds.), *Handbook of autism and pervasive developmental disorders* (pp. 223–246). New York: John Wiley & Sons.
- Cheour, M., Ceponiene, R., Lehtokoski, A., Luuk, A., Allik, J., Alho, K., & Näätänen, R. (1998). Development of language-specific phoneme representations in the infant brain. *Nature Neuroscience*, **1** (5), 351–353.
- Cox, A., Klein, K., Charman, T., Baird, G., Baron-Cohen, S., Swettenham, J., Drew, A., & Wheelwright, S. (1999). Autism spectrum disorders at 20 and 42 months of age: stability of clinical and ADI-R diagnosis. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, **40** (5), 719–732.
- Dalton, K.M., Nacewicz, B.M., Johnstone, T., Schaefer, H.S., Gernsbacher, M.A., Goldsmith, H.H., Alexander, A.L., & Davidson, R.J. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nature Neuroscience*, **8** (4), 519–526.
- Dawson, G., Carver, L., Meltzoff, A.N., Panagiotides, H., McPartland, J., & Webb, S.J. (2002). Neural correlates of face and object recognition in young children with autism spectrum disorder, developmental delay and typical development. *Child Development*, **73** (3), 700–717.
- Dawson, G., Meltzoff, A.N., Osterling, J., & Rinaldi, J. (1998). Neuropsychological correlates of early symptoms of autism. *Child Development*, **69** (5), 1276–1285.
- Dawson, G., Meltzoff, A.N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism and Developmental Disorders*, **28** (6), 479–485.
- Dawson, G., Munson, J., Estes, A., Osterling, J., McPartland, J., Toth, K., Carver, L., & Abbott, R. (2002). Neurocognitive function and joint attention ability in young children with autism spectrum disorder versus developmental delay. *Child Development*, **73** (2), 345–358.
- 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** (3), 403–424.
- de Gelder, B., Vroomen, J., & Van der Heide, L. (1991). Face recognition and lip-reading in autism. *European Journal of Cognitive Psychology*, **3** (1), 69–86.
- de Haan, M., Johnson, M.H., Maurer, D., & Perrett, D.I. (2001). Recognition of individual faces and average face prototypes by 1- and 3-month-old infants. *Cognitive Development*, **16** (2), 659–678.
- Deruelle, C., Rondan, C., Gepner, B., & Tardif, C. (2004). Spatial frequency and face processing in children with autism and Asperger Syndrome. *Journal of Autism and Developmental Disorders*, **34** (2), 199–210.
- Eaves, L.C., & Ho, H.H. (2004). The very early identification of autism: outcome to age 4½–5. *Journal of Autism and Developmental Disorders*, **34** (4), 367–378.
- Fantz, R. (1964). Visual experience in infants: decreased attention to familiar patterns relative to novel ones. *Science*, **146** (3644), 668–670.
- Gepner, B., de Gelder, B., & Scania, D.S. (1996). Face processing in autistics: evidence for a generalised deficit? *Child Neuropsychology*, **2** (2), 123–139.
- Golby, A., Gabrieli, J., Chiao, J., & Eberhardt, J. (2001). Differential responses in the fusiform region to same-race and other-race faces. *Nature Neuroscience*, **4** (8), 845–850.
- Grelotti, D.J., Gauthier, I., & Schultz, R.T. (2002). Social interest and the development of cortical face specialization: what autism teaches us about face processing. *Developmental Psychobiology*, **40** (3), 213–225.
- Grelotti, D.J., Klin, A.J., Gauthier, I., Skudlarski, P., Cohen, D.J., Gore, J.C., Volkmar, F.R., & Schultz, R.T. (2005). fMRI activation of the fusiform gyrus and amygdala to cartoon characters but not to faces in a boy with autism. *Neuropsychologia*, **43** (3), 373–385.
- Griffith, E.M., Pennington, B.F., Wehner, E.A., & Rogers, S.J. (1999). Executive functions in young children with autism. *Child Development*, **70** (4), 817–832.
- Joseph, R.M., & Tanaka, J. (2003). Holistic and part-based face recognition in children with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, **44** (4), 529–542.
- Kaplan, P.S., Werner, J.S., & Rudy, J.W. (1990). Habituation, sensitization, and infant visual attention. In C. Rovee-Collier & L.P. Lipsitt (Eds.), *Advances in infancy research*, Vol. 6 (pp. 61–109). Westport, CT: Ablex Publishing.
- Klin, A., Jones, W., Schultz, R., & Volkmar, F. (2003). The enactive mind, or from actions to cognition: lessons from autism. *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences*, **358** (1430), 345–360.
- Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002a). Defining and quantifying the social phenotype in autism. *American Journal of Psychiatry*, **159** (6), 909–916.
- Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002b). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry*, **59** (9), 809–816.
- Klin, A., Sparrow, S.S., de Bildt, A., Cicchetti, D.V., Cohen, D.J., & Volkmar, F.R. (1999). A normed study of face recognition in autism and related disorders. *Journal of Autism and Developmental Disorders*, **29** (6), 499–508.
- Kotsoni, E., de Haan, M., & Johnson, M.H. (2001). Categorical perception of facial expressions by 7-month-old infants. *Perception*, **30** (9), 1115–1125.

- Kuhl, P.K., Williams, K.A., Lacerda, F., Stevens, K.N., & Lindholm, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science*, **255** (5044), 606–608.
- Leinbach, M.D., & Fagot, B.I. (1993). Categorical habituation to male and female faces: gender schematic processing in infancy. *Infant Behavior and Development*, **16** (3), 317–332.
- Lord, C. (1995). Follow-up of two-year-olds referred for possible autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, **36** (8), 1365–1382.
- Lord, C., Risi, S., Lambrecht, L., Cook, E.H., Leventhal, B.L., DiLavore, P.C., Pickles, A., & Rutter, M. (2000). The Autism Diagnostic Observation Schedule-Generic: a standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders*, **30** (3), 205–223.
- Maestro, S., Muratori, F., Cavallaro, M.C., Pei, F., Stern, D., Golse, B., & Palacio-Espasa, F. (2002). Attentional skills during the first 6 months of age in autism spectrum disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, **41** (10), 1239–1245.
- Maurer, D., & Salapatek, P. (1976). Developmental changes in the scanning of faces by young infants. *Child Development*, **47**, 523–527.
- Mullen, E. (1995). *Mullen Scales of Early Learning*. AGS Edition. Circle Pines, MN: American Guidance Service, Inc.
- Nelson, C.A. (2001). *The development and neural bases of face recognition*. John Wiley & Sons P.R. <http://www.wiley.com/WileyCDA>.
- Osterling, J.A., Dawson, G., & Munson, J.A. (2002). Early recognition of 1-year-old infants with autism spectrum disorder versus mental retardation. *Development and Psychopathology*, **14** (2), 239–251.
- Pascalis, O., & de Haan, M. (Eds.) (2003). Recognition memory and novelty preference: what model? In Harlene Hayne & Jeffrey W. Fagen (Eds.), *Progress in infancy research*, Vol. 3 (pp. 95–119). Mahwah, NJ: Lawrence Erlbaum Associates.
- Pascalis, O., de Haan, M., & Nelson, C.A. (2002). Is face processing species-specific during the first year of life? *Science*, **296** (5571), 1321–1323.
- Pascalis, O., de Haan, M., Nelson, C.A., & de Schonen, S. (1998). Long-term recognition memory for faces assessed by visual paired comparison in 3- and 6-month-old infants. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **24** (1), 249–260.
- Pascalis, O., de Schonen, S., Morton, J., Deruelle, C., & Fabre-Grenet, M. (1995). Mother's face recognition by neonates: a replication and an extension. *Infant Behavior and Development*, **18** (1), 79–85.
- Pascalis, O., Demont, E., de Haan, M., & Campbell, R. (2001). Recognition of faces of different species: a developmental study between 5 and 8 years of age. *Infant and Child Development*, **10** (1–2), 39–45.
- Pascalis, O., Scott, L.S., Kelly, D.J., Shannon, R.W., Nicholson, E., Coleman M., & Nelson, C.A. (2005). Plasticity of face processing in infancy. *Proceedings of the National Academy of Science*, **102**, 5297–5300.
- Pelphrey, K.A., Sasson, N.J., Reznick, J., Paul, G., Goldman, B.D., & Piven, J. (2002). Visual scanning of faces in autism. *Journal of Autism and Developmental Disorders*, **32** (4), 249–261.
- Pierce, K., Haist, F., Sedaghat, F., & Courchesne, E. (2004). The brain response to personally familiar faces in autism: findings of fusiform activity and beyond. *Brain: A Journal of Neurology*, **127** (12), 2703–2716.
- Pierce, K., Mueller, R.A., Ambrose, J., Allen, G., & Courchesne, E. (2001). Face processing occurs outside the fusiform 'face area' in autism: evidence from functional MRI. *Brain*, **124** (10), 2059–2073.
- Quinn, P., Yahr, J., Kuhn, A., Slater, A., & Pascalis, O. (2002). Representation of the gender of human faces by infants: a preference for female. *Perception*, **31** (9), 1109–1121.
- Robinson, A.J., & Pascalis, O. (2004). Development of flexible visual recognition memory in human infants. *Developmental Science*, **7** (5), 527–533.
- Rutter, M., Le Couter, A., & Lord, C. (2003). *ADI-R: Autism Diagnostic Interview-Revised*. Los Angeles, CA: Western Psychological Services.
- Sangrigoli, S., & de Schonen, S. (2004a). Effect of visual experience on face processing: a developmental study of inversion and non-native effects. *Developmental Science*, **7** (1), 74–87.
- Sangrigoli, S., & de Schonen, S. (2004b). Recognition of own-race and other-race faces by three-month-old infants. *Journal of Child Psychology and Psychiatry*, **45** (7), 1219–1227.
- Sangrigoli, S., Pallier, C., Argenti, A., Ventureyra, V., & de Schonen, S. (2005). Reversibility of the other-race effect in face recognition during childhood. *Psychological Science*, **16** (6), 440–444.
- Schultz, R.T. (2005). Developmental deficits in social perception in autism: the role of the amygdala and fusiform face area. *International Journal of Developmental Neuroscience*, **23** (2–3), 125–141.
- Schultz, R.T., Gauthier, I., Klin, A., Fulbright, R.K., Anderson, A.W., Volkmar, F., Skudlarski, P., Lacadie, C., Cohen, D.J., & Gore, J.C. (2000). Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and Asperger syndrome. *Archives of General Psychiatry*, **57** (4), 331–340.
- Sparrow, S.S., Balla, D.A., & Cicchetti, D.V. (1984). *Vineland adaptive behavior scales: interview edition, survey form manual*. Circle Pines, MN: American Guidance Service.
- Stone, W.L., Lee, E.B., Ashford, L., Brissie, J., Hepburn, S.L., Coonrod, E.E., & Weiss, B.H. (1999). Can autism be diagnosed accurately in children under 3 years? *Journal of Child Psychology and Psychiatry and Allied Disciplines*, **40** (2), 219–226.
- Tanaka, J.W., Kiefer, M., & Bukach, C.M. (2004). A holistic account of the own-race effect in face recognition: evidence from a cross-cultural study. *Cognition*, **93** (1), B1–B9.
- Tantam, D., Monaghan, L., Nicholson, H., & Stirling, J. (1989). Autistic children's ability to interpret faces: a research note. *Journal of Child Psychology and Psychiatry*, **30** (4), 623–630.

- Teunisse, J.-P., & de Gelder, B. (2003). Face processing in adolescents with autistic disorder: the inversion and composite effects. *Brain and Cognition*, **52** (3), 285–294.
- Turati, C., & Simion, F. (2002). Newborns' recognition of changing and unchanging aspects of schematic faces. *Journal of Experimental Child Psychology*, **83** (4), 239–261.
- van der Geest, J., Kemner, C., Verbaten, M., & van Engeland, H. (2002). Gaze behavior of children with pervasive developmental disorder toward human faces: a fixation time study. *Journal of Child Psychology and Psychiatry*, **43** (5), 669–678.
- Want, S.C., Pascalis, O., Coleman, M., & Blades, M. (2003). Recognizing people from the inner or outer parts of their faces: developmental data concerning 'unfamiliar' faces. *British Journal of Developmental Psychology*, **21** (1), 125–135.

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