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Face and Object Discrimination in Autism, and Relationship to IQ and Age

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Abstract The current study tested fine discrimination of upright and inverted faces and objects in adolescents with Autism Spectrum Disorder (ASD) as compared to age- and IQ-matched controls. Discrimination sensitivity was tested using morphed faces and morphed objects, and all stimuli were equated in low-level visual characteristics (luminance, contrast, spatial frequency make-up). Participants with ASD exhibited slight, non-significant impairments in discrimination sensitivity for faces, yet significantly enhanced discrimination sensitivity for objects. The ASD group also showed a protracted development of face and object inversion effects. Finally, for ASD participants, face sensitivity improved with increasing IQ while object sensitivity improved with age. By contrast, for controls, face sensitivity improved with age, but neither face nor object sensitivity was influenced by IQ. These findings suggest that individuals with ASD follow a qualitatively different path in the development of face and object processing abilities.

Keywords Autism Spectrum Disorders · Face processing · Object processing · Inversion effects · Adolescents · Development

Introduction

Autism Spectrum Disorders (ASDs) are a cluster of pervasive developmental disorders characterized by abnormalities in social interaction, communication and repetitive/restrictive behaviors (APA DSM-V 2013). Given the social nature of the impairments that characterize ASDs, and the substantial role of face recognition in our daily social interactions, it is perhaps not surprising that many individuals diagnosed with ASD also experience face processing deficits (reviewed in Schultz 2005 and Weigelt et al. 2012). By the time a child is diagnosed with an ASD (usually around 3–5 years of age), there are already clear differences in face processing ability. While 3–5 year old typically developing children appear to engage the same face processing mechanisms as adults, as determined by measures of *holistic processing ability*, i.e., integration of the facial features with their spatial arrangement and the external contour of the face (Macchi Cassia et al. 2009; Pellicano et al. 2006), *configural processing ability*, i.e., the encoding of facial feature distances (e.g., Macchi Cassia et al. 2011; McKone and Boyer 2006; Pellicano et al. 2006), and the *face inversion effect*, i.e., the tendency for inversion to impair the recognition of faces more than objects (e.g., Picozzi et al. 2009; Sangrigoli and de Schonen 2004), it is unclear whether children diagnosed with ASD do the same (reviewed in Sasson 2006 and Weigelt et al. 2012). Here, we provide a brief overview of the face processing literature in children, and then adolescents, with ASD.

Overall, the ability of children with ASD to *holistically process faces*, as measured by tasks such as the composite face effect (i.e., two identical top halves of faces are perceived as different when aligned with different bottom halves, but not when misaligned with different bottom

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halves; Young et al. 1987) and the part-whole effect (i.e., better recognition for facial features when presented in the context of the face; Tanaka and Farah 1993), appears typical and comparable to that seen in typically developing children and adults (e.g., Wilson et al. 2007, 2010b; Wolf et al. 2008; reviewed in Weigelt et al. 2012), with a few important caveats. Although children with ASD are capable of holistically encoding a face, the structure of the resulting face percept appears to be fundamentally different from that of typically developing children. That is, relative to typically developing children, children with ASD often exhibit an attention bias for the lower half of the face and particularly the mouth, and/or a bias away from the eyes and upper half of the face (e.g., Joseph and Tanaka 2003; Wolf et al. 2008; reviewed in Sasson 2006). Likewise, some studies suggest that the face representation encoded by children with ASD is biased toward representing the external features of the face (e.g., hair, ears) rather than the internal features (e.g., eyes, nose, mouth; Wilson et al. 2010b). Thus, while both typically developing children and children with ASD can holistically process a face, the resulting holistic face percept may be very different. In terms of *configural* face processing, there is some suggestion that children with ASD are less sensitive to configural differences than typically developing children. Although children with ASD are good at discriminating differences in eye-mouth distance, they are relatively impaired at discriminating differences in eye–eye distance (Joseph et al. 2008; Wolf et al. 2008). However, in simple face discrimination tasks, e.g., an identity sorting task, ASD and typically developing children perform equally well (simultaneous match-to-sample, Hauck et al. 1998; sorting task, Gepner et al. 1996).

With regard to the relative reliance on *feature*-based versus holistic/configural-based information, some research suggests a preference for feature-based processing in children with ASD (Deruelle et al. 2006; Vlamings et al. 2010; reviewed in Behrmann et al. 2006). This finding is primarily supported by research investigating a bias for different spatial frequencies during face encoding. There are several ways in which to test for a spatial frequency bias. One way has been to compare recognition accuracy for faces filtered to contain different sets of spatial frequencies (e.g., Deruelle et al. 2004; Leonard et al. 2011). Another way has been to measure recognition accuracy for a stimulus containing the spatial frequences of two different faces, e.g., the high spatial frequencies from a happy female face and the low spatial frequencies from an angry male face (e.g., Deruelle et al. 2008). In these experiments, better accuracy for decisions based on high spatial frequency information ($>\sim 25$ cycles per face) reflects a preference for feature-based information, since high spatial frequencies support the perception of fine details. Similarly, better accuracy for decisions based on low spatial frequency information ($<\sim 8$ cycles per face) reflects a preference for configural information, since low spatial frequencies support the perception of face configuration (Goffaux et al. 2011a, b). Many of the experiments using these sorts of paradigms suggest that children with ASD are more likely to make decisions based on high, rather than low, spatial frequencies (i.e., consistent with a feature-based bias), whereas typically developing children display the opposite pattern (Deruelle et al. 2004; emotion results in Deruelle et al. 2008; Vlamings et al. 2010; but see Deruelle et al. 2008; Leonard et al. 2011, for studies suggesting no differences between typically developing children and those with ASD).

This reliance on feature-based processing in ASD is further supported by studies that report a reduced face inversion effect (FIE) in ASD. It is generally believed that the FIE emerges from upright and inverted faces engaging separate mechanisms, whereas upright and inverted nonface objects engage the same mechanisms. More specifically, it is thought that the FIE arises from a shift in encoding style, with upright faces being encoded more holistically and inverted faces encoded more featurally (reviewed in Farah et al. 1998; McKone and Yovel 2009; Young et al. 1987). Because holistic processing is considered more efficient, this leads to better performance in the upright condition (e.g., Goffaux and Rossion 2007; Hole et al. 1999; Maurer et al. 2002; Pallett and MacLeod 2011; Rossion 2008; but see Sekuler et al. 2004, and Richler et al. 2011). With this in mind, the FIE has been used to measure relative reliance on featural versus holistic processing in ASD, with the assumption that observing a smaller FIE in ASD reflects a greater reliance on featural processing in both the upright and inverted face conditions. However, the results of these studies are quite mixed, with some reporting diminished FIEs (Rose et al. 2007; van der Geest et al. 2002) and others reporting normal FIEs (e.g., Bar-Haim et al. 2006; Falck-Ytter 2008; Riby et al. 2009; Rosset et al. 2008; Scherf et al. 2008) in children with ASD. In sum, children with ASD may exhibit many of the traditional hallmarks of face processing ability, but the degree to which they represent faces in a typical fashion remains unclear.

There are surprisingly few studies of face processing in *adolescents* with ASD. The research that does exist suggests that atypicalities in face processing abilities are similar to those found in children with ASD. For example, although adolescents with ASD are capable of holistically encoding a face, the structure of the resulting face percept is often fundamentally different from that formed by typically developing adolescents. Specifically, adolescents with ASD may exhibit a bias for looking toward the mouth region of the face and/or avoiding the eyes (Grossman and

Tager-Flusberg 2008; Rutherford et al. 2007; Wolf et al. 2008). Moreover, experiments using the part-whole and composite face paradigms have suggested that adolescents with ASD may not holistically encode faces as deeply as typically developing adolescents (i.e., they show reduced joint encoding of face parts and configuration; Gauthier et al. 2009; Happé and Frith 2006; López et al. 2004; Teunisse and de Gelder 2003). In terms of configural processing, like children, adolescents with ASD demonstrate greater difficulty discriminating differences in eye–eye distance, but not eye-mouth distance (perhaps due to a mouth bias)(Rutherford et al. 2007). With regard to FIEs, it has been reported that adolescents with ASD exhibit a FIE comparable to that seen in typically developing adolescents (Lahaie et al. 2006; Rutherford et al. 2007; Teunisse and de Gelder 2003). In sum, like children, adolescents with ASD may exhibit many of the traditional hallmarks of face processing ability, but the degree to which they represent faces in a typical fashion remains unclear.

In the current study, we employed well-controlled stimuli and tasks to further address whether there is a face-specific processing deficit for adolescents with ASD, while also attempting to circumvent the methodological shortcomings we believe exist in some of the previous research (see Pallett and Dobkins 2013, for a discussion of this in typically developing individuals). First, most studies investigating the development of face processing in ASD either do not include non-face controls or their control stimuli are not matched well to the face stimuli, making it difficult to determine the extent to which deficits in ASD are *specific* to faces. One notable exception to this are studies that compare the processing of upright faces to inverted faces (e.g., Scherf et al. 2008, and see FIE discussion above), with the obvious advantage that upright and inverted faces (which are one type of control stimulus) are perfectly matched in low-level visual characteristics such as color, luminance, contrast and spatial frequency (discussed further below). There is, however, a drawback to using inverted faces as the non-face control, which is that even though upright versus inverted faces might engage more holistic-based versus feature-based processing mechanisms, respectively, it is uncertain whether inverted faces invoke face or object processing mechanisms. While some research suggests that inverted faces are processed by separate non-face neural mechanisms such as the lateral occipital complex (e.g., Freire et al. 2000; Goffaux and Rossion 2007; reviewed in Rossion 2008), other research suggests that inverted faces are, in fact, processed by face-specific mechanisms (e.g., fusiform face area), albeit less efficiently than upright faces (e.g., Kanwisher et al. 1998; Richler et al. 2011; Sekuler et al. 2004; reviewed in Valentine 1988).

Because of the drawbacks of using inverted faces, perhaps the most suitable control stimuli for faces are other objects, such as cars, toys or animals (e.g., Boucher and Lewis 1992; Wilson et al. 2010a, b; for a review see Weigelt et al. 2012). However, here, the challenge is to equate the two stimulus types in terms of low-level visual characteristics (color, luminance, contrast, spatial frequency). If this is not done, then differences observed between ASD and typical individuals in face versus object processing could result from group differences in sensitivity to low-level visual features. For example, imagine that the face stimuli employed in a given study are composed of much lower spatial frequencies than the object stimuli. If, then, individuals with ASD underperform typical individuals on the face, but not the object, task, this could be due to (1) impaired face processing mechanisms in ASD and/or (2) impairments in the mechanisms tuned for low spatial frequencies. To our knowledge, research on individuals with ASD has not carefully considered this possibility. It is, however, important to point out that even when the low-level visual characteristics for faces and objects are equated, direct comparisons between face and object performance pose an "apples versus oranges" problem, because the particular face and object stimuli chosen for a given study are likely to be inherently different in how difficult they are to discriminate/process in the task being tested. For example, imagine that the task is to discriminate featural changes in faces (e.g., eye color/shape) versus objects (e.g., the tires of a car). Performance on the tasks will depend on how different the face features are versus how different the car features are, making a comparison between the two impossible. For this reason, the only fair comparison is one that asks whether individuals with ASD differ from typically developing individuals in their *relative* processing of faces versus objects. Statistically, this should appear as an interaction between participant group (ASD vs. typical) and stimulus type (faces vs. objects). This might be driven by group differences in face performance, object performance or both.

To address these methodological issues, the current study measured face and object discrimination in adolescents with ASD and age-matched, typically developing adolescents. We have previously used this paradigm successfully to measure the development of face and object processing between childhood and adulthood in typically developing individuals (Pallett and Dobkins 2013). The objects were pictures of cars, equated in their low-level visual characteristics with the faces (i.e., color, luminance, contrast and spatial frequency), and the same discrimination task was used for both faces and cars. The discrimination task used morphed faces (morphed between Face 1 and Face 2) and morphed cars (morphed between Car 1 and Car 2), with participants reporting whether a given morph was more similar to Face 1 versus Face 2 (or Car 1 vs. Car 2), as in previous studies of neurotypical individuals (e.g., Pallett and Dobkins 2013; Pitcher et al. 2009; Tanaka and Corneille 2007). We obtained discrimination thresholds using a staircase design, which equates the difficulty of the tasks across stimulus types and participants because the staircase homes in on 80 % correct performance. We believe that obtaining thresholds is preferable to methods that obtain percent correct performance (as in much of the previous face processing research in ASD), because the latter can suffer from floor and ceiling problems.

In addition to these methodological issues, the current study also attempted to address the thorny issue of adequately matching the ASD participants with typically developing controls. There have been a variety of ways employed in previous literature, including matching on chronological age, mental age, and/or IQ, and the quality of matching can vary highly across studies (see Jarrold and Brock 2004, for discussion). In the current study, we carefully matched on IQ, chronological age, gender, ethnicity and handedness, any of which might affect face processing performance. Despite our careful matching, with nearly identical age and IQ distributions between groups, there is always some remaining variation across participants in age and IQ, albeit small. For this reason, we felt it important to additionally investigate the effects of age and IQ on face and object discrimination, to determine if these factors contributed to our results (for a greater description of methodological concerns in ASD research, see Jarrold and Brock 2004). The findings of our study revealed dissociative processing of faces versus objects between ASD and typically developing individuals that stemmed, in part, from differences in object discrimination performance. In addition, we found interesting—and dissociative between groups—effects of age and IQ on performance.

Methods

Participants

A total of 14 adolescents with ASD and 14 typically developing (TD) adolescents contributed to the data in this study. They were recruited from community resources in San Diego and the San Diego Unified School District. The participants with ASD were diagnosed by a licensed clinical psychologist or medical doctor not associated with this research, based on DSM-IV-TR criteria (APA 2004), and confirmed in our laboratory using the Autism Diagnostic Observational Schedule (ADOS, see "Psychometric Assessments", below). These participants had no known specific neurological or genetic conditions (e.g., Fragile X, Rett Syndrome) that could account for their diagnosis of ASD. Written informed consent was obtained from all participants, as well as from their parents. Each parent and participant received $5 per visit, unless they indicated on the consent form that they wished to participate for free. The study took 2–3 hours to complete. All participants had normal or corrected to normal vision. The procedures followed were in accordance with the ethical standards of the UC San Diego Human Research Protection Program and the 1964 Declaration of Helsinki.

The external diagnoses of the 14 participants with ASD were: eight with Autistic Disorder, four with Asperger's Syndrome, and one with pervasive developmental disorder not otherwise specified (PDD-NOS). Table 1 presents group age, gender, race, handedness (assessed with the Edinburgh Handedness Index; Oldfield 1971) and IQ, which did not differ between the control and ASD groups. As expected, the two groups differed in assessments of ASD symptoms (described in "Psychometric Assessments", below). There were no significant outliers within either participant group for the demographic data (defined as greater than 2.75 SD from the mean).

Psychometric Assessments

All participants were assessed using the Social Communication Questionnaire (SCQ; Rutter 2003), which asks about the presence or absence of 40 Autism-related behaviors (cut-off score: 15), and the Social Responsiveness Scale (SRS; Constantino et al. 2000), which asks about the frequency of 65 Autism-related behaviors (no cut-off score exists for this, however the published mean score for persons with PDD-NOS is 101.5 with a standard deviation of 23.6). The SCQ and SRS were completed by the parents. As expected, the ASD and TD groups differed in SCQ and SRS scores. Intelligence was assessed using the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler 1939), which rendered a "verbal IQ", "performance IQ", and a "full scale IQ". Finally, the diagnosis of all ASD participants was confirmed using the ADOS (Lord et al. 2000). Group means, SDs and *p* values for the differences between groups from these assessments are presented in Table 1. Means for ADOS scores are not presented because they are not standardized scores.

Stimuli

The stimuli consisted of faces and cars presented on a 51 cm high resolution RGB Sony CRT monitor (1,280 × 1,024 pixel, 75 Hz) using Matlab 7.3 and the Psychophysics Toolbox (Brainard 1997; Pelli 1997). The stimuli were created from two frontal photographs of Caucasian females and two side profile photographs of cars, which we refer to as "template" stimuli. Faces subtended 8.1° × 11.3° and cars

Table 1 Demographic data

	ASD (N = 14)		TD (N = 14)		Statistics
	Count	Percentage	Count	Percentage	
Gender	10 boys 4 girls	71 29	10 boys 4 girls	71 29	Fisher's Exact: $p = 1$
Handedness	11 right 3 left	79 21	11 right 3 left	79 21	Fisher's Exact: $p = 1$
Race	11 Caucasian 3 other	79 21	9 Caucasian 5 other	64 36	Fisher's Exact: $p = 0.68$

	Mean	SD	Range	Mean	SD	Range	Statistics
Age (years:months)	15:3	1:6	13:0–17:10	15:5	1:4	13:2–17:5	F(2,28) = 0.55, $p = 0.82$
Verbal IQ	103.9	14.1	76–127	105.1	15.7	79–138	F(2,28) = 0.047, $p = 0.83$
Performance IQ	107.1	14.5	79–129	105.0	9.97	88–124	F(2,28) = 0.20, $p = 0.66$
Full Scale IQ	105.2	15.0	76–132	107.0	13.1	79–132	F(2,28) = 0.11, $p = 0.74$
SCQ Score	24.8	7.58	6–35	2.57	2.56	0–8	F(2,28) = 107.6, $p < 0.001$
SRS Score	97.5	25.9	56–135	50.3	8.00	36–63	F(2,28) = 42.5, $p < 0.001$

subtended 19.8° × 6.7°.[1] The four template stimuli are shown in Fig. 1a. We chose cars as stimuli because, like faces, cars are generally viewed in a single orientation (i.e., upright), and our exposure to cars from infancy onwards is extensive. Cars also make good control stimuli since they vary in both their features (e.g., type of wheels, style of door, number of doors, etc.) and their configurations (e.g., aspect ratio, distance between the wheels relative to car length, distance between the front window and front lights relative to car length, etc.). Similar to faces, it can also often be necessary to identify a familiar car (i.e., your car) from a large "crowd" of cars (e.g., in a parking lot). There are very few other objects (biologically based or man-made) for which we have that experience. For these reasons, we believe cars make good control objects. We chose side profiles for cars rather than frontal profiles, since the front of a car may be perceived as face-like (e.g., lights for eyes, etc.).

To prepare these images for presentation, the first step was to linearize the luminance values of all images. The reason for this is that on video monitors, there is a non-linear relationship between gun values and the luminances, referred to as a "gamma" function, which is a power function that usually has an exponent of 2.2 on monitors. Because digital images are intended to be displayed on monitors, the luminance values of the original image are compressed (in JPEG, BITMAP, etc.) with an inverse-gamma function (~1/2.2). As a consequence, when the compressed image is presented on a video monitor, the original luminance values of images are recreated (thereby making a person's face look like the actual, original face). Because we wanted complete control over the mean luminances, contrasts, and spatial frequency content of all of our stimuli (equating these parameters across images), our first step was to convert the digital images (which were in JPEG or BITMAP) *back* to their original luminance values by passing them through an inverse-gamma function. After normalizing all of our images (mean luminance, contrast, spatial frequency content) in this "true" luminance space, we then presented these values on a gamma-corrected (i.e., calibrated) video monitor.

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[1] Unfortunately, due to a glitch in our program, our faces and cars were not equated in size; however the differences in size were not very large. And, previous research has shown that the neural mechanisms underlying face and object processing are largely invariant to changes in size (Zhao and Chub 2001; Yamashita et al. 2005; Rolls et al. 1992; Grill-Spector et al. 1999).

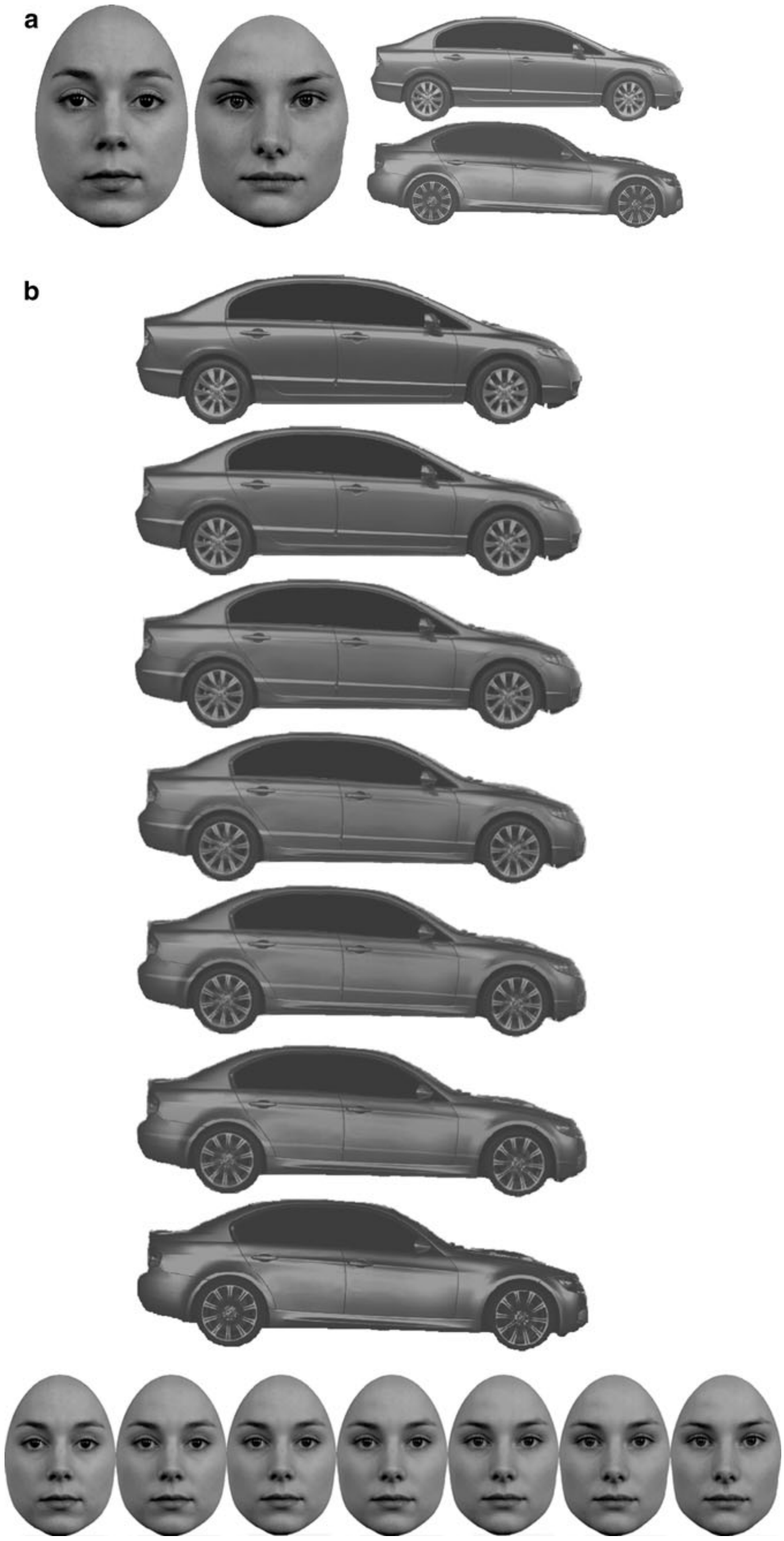

Fig. 1 **a** Face Templates (Face 1 and Face 2) and Object (car) templates (Car 1 and Car 2). **b** Examples of morphed test stimuli. 100 morphs were created between 100 % Face1/0 % Face 2 and 100 % Face2/0 % Face 1 (and likewise for cars). *Seven morphed faces* and *seven morphed cars* are shown here. Since we do not have permission to publish the faces from the experiment, as an example of morphs, we show faces from the Radboud Faces Database (Langner et al. 2010)

There were several aspects of the low-level image characteristics that were manipulated to equate the face and car stimuli. Note that these manipulations were applied only to the stimulus portion of the image and not the background upon which they were placed. This ensured that any performance differences observed between the face versus car task could not be accounted for by differences in low-level visual spatial characteristics.

1. All images were converted to *gray scale* in Adobe Photoshop.
2. The *mean luminance* of the face and object images was manipulated by determining the mean luminance of the original image and multiplying each point by a value that would make the mean luminance the desired value. The mean luminance of all images was 15.17 cd/m^2.
3. The *root-mean-squared (rms) contrast* of the face and object images was manipulated, where rms contrast is described as follows, which is equivalent to the standard deviation of the pixel intensities:

$$C_{\mathrm{rms}} = \sqrt{\frac{\sum L^2_{(\mathrm{x,y})} - \frac{\sum L^2_{(\mathrm{x,y})}}{N}}{N}}$$

where C_{rms} is rms contrast, L is the luminance of a given pixel, N is the total number of pixels and x and y represent the position (row and column) of each particular pixel. Rms contrast for an image was manipulated by, first, determining the rms contrast of the luminance-adjusted image, and then dividing each image-pixel value by a ratio (rms contrast of the luminance-adjusted image/desired rms contrast) to make the total rms contrast of the image the desired value. The root-mean square contrast of all images was 48.9.

4. The *Spatial Frequency Content* of images was measured using fast Fourier transform (FFT) (see Bosworth et al. 2006). In FFT, images are described by a linear function in log-energy versus log-SF space, where the height of this function (i.e., its vertical position) reflects the total contrast in the image, and the slope reflects the relative contrast at different SFs. Since there were no significant differences between the slopes of our faces and objects (mean slope = −1.56), no additional manipulations were needed to equate spatial frequency content.

After this normalization process, the template stimuli were morphed together to create a series of 100 "test" stimuli ranging from 100 % Face 1/0 % Face 2 to 0 % Face 1/100 % Face 2 (and likewise for cars). Example morphs are presented in Fig. 1b. All images were placed on a rectangular white background (60.5 cd/m^2) and were presented against a gray background (30.3 cd/m^2). Note that morphing stimuli will create changes in both the features and the configuration of the stimuli, and thus this manipulation does not aim to test the two dimensions (featural and configural) separately.

Procedures

Participants were tested in a dimly lit room and viewed the display binocularly at a distance of 50 cm. On each trial, a small fixation cross appeared for 500 ms after which three stimuli were presented simultaneously. Two "template" stimuli, Face 1 and Face 2 or Car 1 and Car 2, appeared in the upper left and right corners of the display, respectively (Faces: centered 12.3° horizontally and 8.03° vertically from the middle of the monitor, Cars: centered 9.53° horizontally and 8.63° vertically from the middle of the monitor).[2] The test face (or car), which was a morph between Face 1 and Face 2 (or between Car 1 and Car 2), appeared in the lower half of the display (centered 10° below the middle of the monitor). All three stimuli were either upright or inverted, and all stimuli remained visible until the participant indicated whether the test face looked more like Face 1 or Face 2 (and likewise for cars). After the participant responded, the next trial began 300 ms later. In order to obtain discrimination thresholds, the test face (or car) varied across trials (i.e., in its percent of Face 1 vs. Face 2, or percent of Car 1 vs. Car 2) in a staircase design (see "Staircase Design", below).

Participants responded with key presses ("left" vs. "right") on a keyboard. A beep indicated a correct response, which was considered a selection of Face 1 when the morph contained more than 50 % of Face 1 and a selection of Face 2 when the morph contained more than 50 % of Face 2 (likewise for cars). This feedback was provided to keep participants engaged in the task.

Staircase Design

To obtain each participant's face and car thresholds, an adaptive staircase procedure was employed in which the percentage of the two template stimuli, Face 1 versus Face

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[2] Note that template Face 1 is always on the left side and template Face 2 is always on the right side. The reason we did not counterbalance the location of Face 1/Face 2 across trials is because this paradigm had been part of a study comparing typically developing children (4–5 year olds) with adolescents (Pallett and Dobkins 2013), where we wanted to keep things as simple as possible for the children. Because we did not counterbalance, if a participant had a bias to respond "left" rather than "right" (or vice versa), this would result in them doing better at matching the test face with Face 1 (on the left side) than with Face 2 (on the right side) (or vice versa). This is not expected to be a problem, however, because we take the average of the thresholds for matching the test face to Face 1 and Face 2, so biases should average out (and likewise for cars).

2 (or Car 1 vs. Car 2), contained in the test (morph) stimulus varied across trials. Upright Face, Inverted Face, Upright Car and Inverted Car data were collected in separate blocks. Within a block of trials, there were two interleaved staircases. One staircase determined the threshold for Face 1 (or Car 1), with threshold defined as the test stimulus that yielded 80 % "most similar to" matches to Face 1. The other determined the threshold for Face 2 (or Car 2), in a likewise manner. On the first trial of the staircase isolating the threshold for Face 1 (or Car 1), the test stimulus was presented at 80 % Face 1/20 % Face 2 (or 80 % Car 1/20 % Car 2) and similarly for the staircase isolating the threshold for Face 2 (i.e., 80 % Face 2/20 % Face 1). The test stimulus for subsequent trials varied in a 1 down/4 up procedure, based on a modified PEST method (see Taylor and Creelman 1967). That is, in the staircase isolating the threshold for Face 1, the test stimulus decreased in similarity to the template (e.g., Face 1) by one step size after a "Face 1" response and increased in similarity to the template by four step sizes following a "Face 2" response. The value of the step size was determined by an acceleration factor of 1.2 and a reversal factor of power of 1.6. Following either two correct or two incorrect responses, the step size was multiplied by the acceleration factor. The maximum step size was 20 morph units. Following a reversal in correctness, the step size was multiplied by (1/acceleration factor)^reversal power. In addition, after every 10 trials participants viewed an easy trial in which the test stimulus was identical to one of the two template stimuli (e.g., 100 % Face 1/0 % Face 2).

Stimuli were presented in eight blocks of trials, two for upright faces, two for inverted faces, two for upright cars, and two for inverted cars (car staircases analogous to face staircases, explained above). Order was semi-randomized such that each stimulus type was viewed once before repetition occurred. The condition viewed first was counterbalanced across participants. Participants viewed 50 trials per block, for 400 total test trials (and 40 additional easy trials, which were either 100 % Face 1/0 % Face 2 or 0 % Face 1/100 % Face 2 and likewise for blocks with cars).

Data Analyses

Thresholds were determined by fitting the proportion of matches to a given template for each participant and each stimulus type to a logistic function.[3] Specifically, psychometric functions were produced by using psignifit version 2.5.6 (see http://bootstrap-software.org/psignifit/), a software package that implements the maximum-likelihood method described by Wichmann and Hill (2001) and runs in Matlab. Two thresholds were determined; the test stimulus that yielded 80 % matches to Face 1 in the staircase isolating the threshold for Face 1, and the test stimulus (i.e., morph level) that yielded 80 % matches to Face 2 in the staircase isolating the threshold for Face 2. Face discrimination thresholds were calculated as the average of these two. (The same applied for car discrimination thresholds.) Thresholds were then converted into sensitivity measures, which is the inverse of threshold. Sensitivity data were logged because logged, and not linear, data conform to normal distributions. Accordingly, large sensitivity values indicate good discrimination and small sensitivity values represent poor discrimination.

Log sensitivity data were analyzed in a three-factor (*stimulus type*: face vs. car × *orientation*: upright vs. inverted × *group*: TD vs. ASD) ANCOVA, with age and IQ included as covariates. This allowed us to remove variance due to IQ/age, in addition, we conducted linear regression analyses to assess the relationship between IQ/age and object sensitivity and the relationship between IQ/age and face sensitivity, separately for the two subject groups. Finally, because we wanted to ensure that any group differences in sensitivity were not secondary to differences in response times, for example, one group might perform better than another group because they take longer to respond, we conducted analyses on response times. An ANCOVA conducted on response times, with age in months and IQ as covariates, revealed no differences between the ASD and TD groups and no 2-way or 3-way interactions between subject groups, stimulus type and orientation (all ps > 0.16). We therefore do not discuss response times further in this paper.

Results

ANCOVA

The results of the three-factor ANCOVA (with age and IQ as covariates) revealed no main effects of participant group or stimulus type (group: $F(1, 24) = 0.11$, $p = 0.74$; stimulus type: $F(1, 24) = 2.07, p = 0.16$), but there was a main effect of orientation ($F(1, 24) = 5.62, p = 0.026$, $\eta_p^2 = 0.19$) with better performance for upright stimuli. There was also a significant stimulus type × participant group interaction ($F(1,24) = 5.50$, $p = 0.028$, $\eta_p^2 = 0.19$), but no three-way stimulus type × orientation × group interaction ($F(1, 24) = 0.53, p = 0.48$). (Main effects and interactions tied to the covariates are described in "Effects of covariates: Age and IQ", below). To determine what drove the stimulus type × group interaction, we collapsed the data across orientation and conducted two one-factor ANCOVAs, one to examine the effect of participant group on face discrimination, and the other to examine the effect of group on object discrimination. Results from these analyses revealed that the

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[3] Data from the "easy trials" were not included in this analysis.

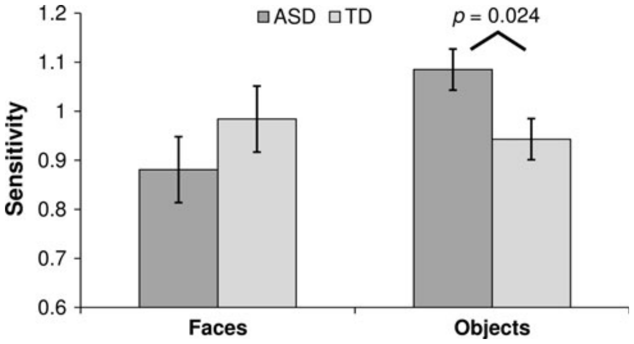

Fig. 2 Means and SEs (±) for face and object discrimination in adolescents with ASD (N = 14) and typically developing adolescents (N = 14). Means and SEs were adjusted for the effects of covariates (IQ = 105; age = 15.4 years). Higher sensitivity means better performance

stimulus type × group interaction was driven by the ASD group outperforming the TD group on object discrimination ($F(1, 24) = 5.79$, $p = 0.024$, $\eta_p^2 = 0.27$), whereas the two groups performed comparably on face discrimination, with a slight, non-significant impairment in the ASD group ($F(1, 24) = 1.17$, $p = 0.29$). (Main effects and interactions tied to the covariates are described in "Effects of covariates: Age and IQ", below). Figure 2 shows the mean face and object sensitivities for TD and ASD participants, after adjustment for the covariates.

Effects of Covariates: Age and IQ

As might be expected, the results of the three-factor ANCOVA revealed a main effect of age ($F(1, 24) = 8.13$, $p = 0.009$, $\eta_p^2 = 0.19$), with better overall performance for older participants ($r = 0.41$, $p = 0.035$). There was also an orientation × age interaction ($F(1, 24) = 4.71$, $p = 0.04$, $\eta_p^2 = 0.16$), which means the main effects of orientation (described above) and age need to be reinterpreted. Specifically, the interaction appeared driven by larger orientation effects with increasing age (which we return to below, under *Effects of Orientation*). Interestingly, the three-factor ANCOVA also revealed a stimulus type × IQ interaction ($F(1, 24) = 7.38$, $p = 0.012$, $\eta_p^2 = 0.24$). [There was no three-way stimulus type × orientation × IQ interaction or stimulus type × orientation × age interaction (Fs < 0.50, ps > 0.60).] To further determine what drove this stimulus type × IQ interaction, we examined not only the independent influence of IQ on face sensitivity or object sensitivity, but also the possibility of a further relationship with group and age using linear regression. [This could also be looked at with a 5-factor ANCOVA that includes interactions between all variables in its model. However, our ANCOVA model did not include interactions between IQ, age and group since our primary goal was to minimize the influence of covariates, and the ability to detect an effect with a 5-factor ANCOVA would be limited by power.]

We performed four separate linear regressions to investigate the relationship of IQ and age with: (1) face sensitivity in ASD participants, (2) object sensitivity in ASD participants, (3) face sensitivity in TD participants and (4) object sensitivity in TD participants. In these analyses, we collapsed across upright and inverted orientation since in the three-factor ANCOVA, the IQ × stimulus type interaction did not further interact with orientation. Importantly, the variance of IQ, age, face sensitivity and object sensitivity did not differ significantly between the two groups (Levene's test, all $F < 0.50$ and $p > 0.50$), thus allowing us to conduct the linear regressions. Notably, this is an important requirement for group comparisons that is often missing from reports of ASD research. Although many ASD studies equate the means of the ASD and control groups on factors such as age or IQ, variability in these measures can differ markedly between the two groups.

The results of these linear regressions revealed different patterns for the ASD and TD groups (see Fig. 3). For the ASD group, face sensitivity was marginally predicted by IQ ($R^2 = 0.23$, $t = 1.91$, $p = 0.082$), but not age ($R^2 = 0.0038$, $t = 0.57$, $p = 0.58$), while object sensitivity was predicted by age ($R^2 = 0.43$, $t = 2.53$, $p = 0.028$), but not IQ ($R^2 = 0.10$, $t = 0.26$, $p = 0.80$). A different pattern was seen for the TD group. Here, face sensitivity, and to a much lesser extent object sensitivity, were predicted by age (face: $R^2 = 0.35$, $t = 2.25$, $p = 0.046$; object: $R^2 = 0.18$, $t = 1.80$, $p = 0.10$), but neither face nor object sensitivity was predicted by IQ (face: $R^2 = 0.044$, $t = 1.12$, $p = 0.29$; object: $R^2 = 0.18$, $t = 0.68$, $p = 0.51$). In sum, these results suggest that the stimulus type × IQ interaction seen in the original three-factor ANCOVA was driven primarily by a trend for IQ to predict face sensitivity in the ASD participants only, with higher IQ predicting higher face sensitivity. These linear regression results also suggest that the effect of age in the original three-factor ANCOVA were driven by an effect of age on *face* sensitivity (and perhaps also object sensitivity) in the TD group and an effect of age on *object* sensitivity in the ASD group (but interestingly, not face sensitivity).

Effects of Orientation

As mentioned above, the three-factor ANCOVA (which included IQ and age as covariates) revealed an age × orientation interaction ($F(1, 24) = 4.71, p = 0.04, \eta_p^2 = 0.16$). To investigate what drove this interaction, and specifically ask whether it differs between participant group, for each participant, we collapsed the data across faces and objects (since stimulus type had no three-way interaction with the orientation × age interaction in the ANCOVA) and gave each participant an "Inversion Effect" measure, defined as

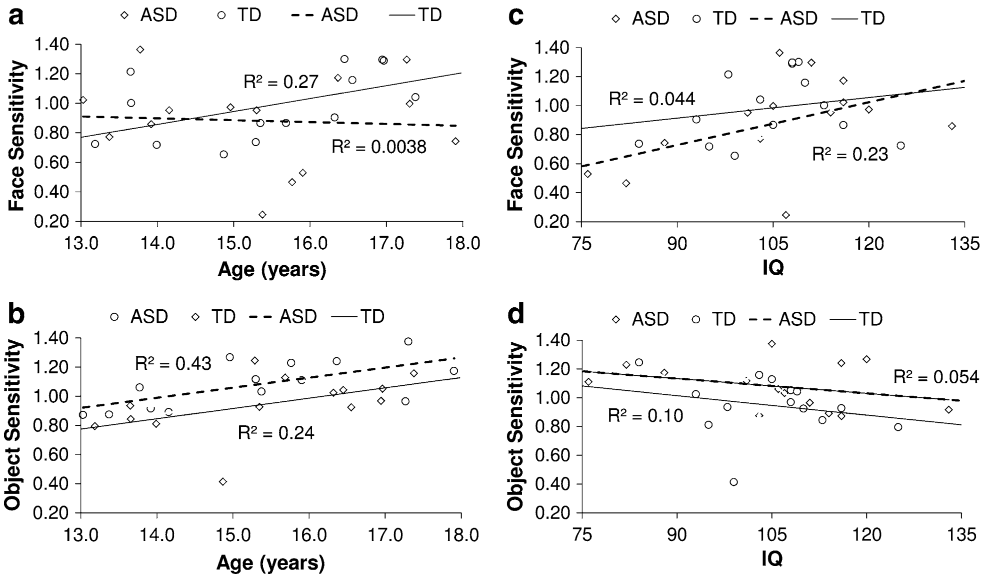

Fig. 3 *Top left* The relationship between face discrimination and age for adolescents with ASD (N = 14) and typically developing adolescents (N = 14). *Top right* The relationship between face discrimination and IQ for adolescents with ASD and typically developing adolescents. *Bottom left* The relationship between object discrimination and age for adolescents with ASD and typically developing adolescents. *Bottom right* The relationship between object discrimination and IQ for adolescents with ASD and typically developing adolescents

the difference in log sensitivity for upright versus inverted images, with values greater than 0 indicating an inversion effect. Then, in two separate partial correlations, one for the ASD group and one for the TD group, we asked whether age predicts the size of the inversion effect when the effect of IQ is taken into account [Note that we analyzed it this way, since, as we say above, our ANCOVA model did not include interactions between covariates and group, allowing us to see if there is a age × orientation × participant interaction]. The results of this partial correlation for the TD participants showed no relationship between age and inversion effect ($r = 0.25$, $p = 0.41$). By contrast, for the ASD group, the size of inversion effects increased significantly with age ($r = 0.69$, $p = 0.013$). This correlation suggests that inversion effects for basic face and object discrimination (as tested in the current study) may be weak and slow to develop in ASD. This is consistent with the mixed findings for FIEs in individuals with ASD (see "Introduction" section).

Discussion

The current study tested both face processing and object (car) processing in adolescents with ASD and typically developing (TD) controls. This study differs from previous research in three important ways. First, our stimuli were equated in their low-level visual characteristics (i.e., luminance, contrast and spatial frequency make-up), ensuring that any effect of group that differed between face and object processing could not be a result of low-level differences between the two stimulus types. Second, we used a staircase method to obtain discrimination thresholds, which equated the level of task difficulty between stimuli and participant groups (staircase homed in on 80 % correct performance). Third, control participants were *carefully* demographically matched with the ASD group, including on factors that are traditionally harder to equate, e.g., gender and IQ. To our knowledge, this is the first study to apply such a carefully calibrated approach to the investigation of face and object processing in ASD.

Under these rigorous conditions, we found that individuals with ASD exhibited slight, non-significant impairments in face sensitivity, and significantly enhanced object sensitivity. Our results also showed that for TD individuals, age was a significant predictor of face, but not object, sensitivity. This result is in line with the general idea that face processing typically develops more slowly than object processing, with some aspects of face processing developing into adulthood (e.g., Germine et al. 2011; reviewed in McKone et al. 2009; Pascalis et al. 2011; Pallett and Dobkins 2013), while object processing appears adult-like by 4- to 5-years (see Pallett and Dobkins 2013, for a review). The novel aspect of the current results is that the opposite pattern was seen for individuals with ASD, i.e., age was a predictor of object, but not face, sensitivity, and face sensitivity was instead predicted by IQ (which was not true for TD participants).

In the remainder of this *Discussion*, we first address possible reasons for discrepancies across studies regarding face processing deficits in ASD, as well as a possible explanation for why we did not observe selective face inversion effects, as is often reported in other studies. We then discuss face processing development in ASD, the observed relationship between IQ and face sensitivity and how individuals with ASD may employ alternative strategies for face processing tasks. Finally, we discuss the evidence for enhanced object processing in the current study as well as in previous studies of children with ASD.

Discrepanices Across Studies

Many, but not all, studies of face processing in ASD have reported decifits (see *Introduction,* reviewed in Weigelt et al. 2012), whereas the current study found only a slight, non-significant deficit in face sensitivity. First, the most obvious explanation for our finding a weak effect is sample size. We think this reason is unlikely, however, since our sample size (N = 14) was larger than the sample sizes of other studies that have revealed significant face perception deficits in individuals with ASDs (e.g., Boucher and Lewis 1992; Rinehart et al. 2000), and was large enough to reveal a significant group difference in object sensitivity. A second possibility is that individuals with ASD show deficits on some, but not all, face processing tasks. Specifically, it has been suggested that face processing deficits in ASD are greatest when there is a memory component, for example, when using the sequential presentation of stimuli (see Weigelt et al. 2012, for review). The task of the current study had no memory component, and for this reason may not have revealed a face processing deficit. A third possibility is based on the fact that the current study found a relationship between IQ and face processing in ASD participants (where ASD individuals with higher IQs exhibited better face sensitivity than those with lower IQs). Given this, it is possible that reports from previous studies of face processing deficits in ASD were driven by lower (albeit, small and non-significantly different) IQs in the ASD group than the TD group. A similar argument could be made for age. If there are age-related increases in face sensitivity (as seen in the TD group of the current study), it is possible that reports from previous studies of face processing deficits in ASD could have arisen if the TD group were slightly older than the ASD group. Even if age is well-matched between ASD and TD participants, it still may be that deficits in face perception in ASD are age dependent, a notion that is supported by data from O'Hearn et al. (2010) showing that the gap between ASD and TD individuals in face processing abilities increases with age into adulthood. In line with this, the current study found that face discrimination improves with age for TD, but not ASD, participants, suggesting that had we tested participants older than adolescents, we might have expected to see the TD group outperform the ASD group.

One curious result we observed, in the context of the face processing literature in general, is that there was no interaction between object type (faces, cars) and orientation (upright, inverted), i.e., inversion effects were no greater for faces than for objects. This results is not in line with much of the literature showing that inversion effects are greater for faces than for objects (i.e., a "selective FIE"), which, in fact, is seen as one of the behavioral hallmarks used to distinguish face processing from other types of non-face processing. We believe that the lack of a selective face inversion effect in the current study may be due to the task and/or stimuli inducing an analytic (feature-based) encoding approach, which lessened the inversion effect for faces, making it indistinguishable from the inversion effect seen for objects. Consistent with this possibility, results from a study by Pallett and MacLeod (2011) suggest that our experiment task, i.e., relative judgments (more like Face 1 or Face 2), may reduce effects of inversion for discrimination sensitivity. It is important to point out, however, that the fact that inversion effects did not differ between faces and objects in the current study does not indicate that the face and object tasks tapped the *same* underlying mechanism. We strongly believe the face and objects stimuli/tasks tapped difference mechanisms because of other differences observed between faces and objects, i.e., (1) group differences for object, but not face, sensitivity, and (2) effects of IQ on face, but not object, sensitivity in ASD participants. On a final note, although the current study did not find selective FIEs, the results nonetheless revealed an age-related increase in the magnitude of the inversion effect (collapsed across faces and objects) in ASD individuals, but not in TD individuals. Such findings suggest that ASD individuals continue to get better at higher-level visual processing as they get older.

Face Processing Development in ASD

Considering the observed relationship between IQ and face discrimination sensitivity, and the protracted development of inversion effects in our ASD group, we propose that individuals with ASD may develop unique strategies to compensate for possessing partially impaired face processing mechanisms, (see Behrmann et al. 2006 for review of this possibility, and Introduction). For example, if holistic face processing mechanisms are impaired or the resulting holistic percept is qualitatively different (e.g., mouth or external facial feature bias) in ASD, then these individuals may learn to pay closer attention to featural information and use that to discriminate one face from another. In addition, it may be that those individuals with higher IQs are more likely to tap into compensatory strategies/mechanisms when processing faces, which would account for the correlation observed between IQ and face discrimination performance in the ASD group only. These strategies may be mediated by neural activation in regions not traditionally associated with the face processing network (Haxby et al. 2000). For example, neuroimaging (fMRI) studies in ASD have reported less-than-normal activation to faces in the fusiform face area (FFA) (reviewed in Dalton et al. 2005; Golarai et al. 2006; Morita et al. 2011), a neural region implicated in the processing of faces (Kanwisher et al. 1997), yet greater-than-normal activation to faces in the object-sensitive regions of the brain (Hubl et al. 2003; Pierce et al. 2001; Schultz et al. 2000). In addition, neural regions associated with social cognition (e.g., prefrontal cortex) have been shown to respond during face processing tasks in ASD, but not controls (Bookheimer et al. 2008; Hubl et al. 2003; Pierce et al. 2001). When considered alongside recent face processing research suggesting that a variety of factors, such as hormones and motivation, may influence the development of face discrimination ability, there is an increasingly complex picture of potential sources for ASD versus TD deviations (see Scherf et al. 2012). As such, the fact that the current study revealed relatively typical face discrimination abilities in adolescents with ASD may reflect the use of neural regions outside of face processing areas (e.g., prefronal cortex) during our face task. Along these lines, Morita et al. (2011) reported typical behavioral performance on a face processing task yet less-than-typical FFA activation in response to faces in ASD participants. Taken together, these findings suggest that typical performance on face processing tasks in ASD may be accomplished through an atypical face processing network and/or alternate, cognitive-based strategies.

Enhanced Object Processing in ASD

The current study revealed superior object discrimination sensitivity in individuals with ASD, although the effect size was rather small ($\eta_p^2 = 0.19$). In addition, object sensitivity increased significantly with age (between the ages of 13 and 17.8 years) in the ASD participants, which was not the case for the TD participants. Although our observation of enhanced object processing may at first glance seem surprising, there are in fact similar previous reports in the literature. For example, individuals with ASD have been reported as being better at discriminating differences in houses than TD participants (Wolf et al. 2008). In addition, there are reports that young children with ASD exhibit *increased* looking times to, and exploration of, non-face objects relative to TD children (e.g., Ozonoff et al. 2008; Swettenham et al. 1998; Zwaigenbaum et al. 2005; but see Maestro et al. 2002, and Baranek 1999). Data from functional magnetic resonance imaging (fMRI) studies suggest that individuals with ASD engage the object processing regions of the brain more than typical controls during an embedded figures task (whereas controls exhibit a greater reliance on neural regions subserving memory; Damarla et al. 2010; Ring et al. 1999). Moreover, evidence from our laboratory suggests that atypical neural processing of objects might be an early risk factor in the development of ASD, as measured in 10-month-old “high-risk” infants who have an older sibling with ASD and are therefore thought to carry some of the genes associated with ASD. Using event-related potentials (ERP), we reported that compared to low-risk control infants (i.e., without ASD family history), high-risk infants showed atypically fast object responses (in the P400 and N290). By contrast, face responses in high-risk infants looked typical (McCleery et al. 2009).

Given the previous literature in younger children, the results of the current study suggest that the enhanced perceptual discrimination of objects observed for ASD starts early in childhood and is maintained into adolescence. The possibility of enhanced object discrimination in ASD is consistent with the confluence of two other notions in the literature: (1) that object processing relies more on local, feature-based information (reviewed in McKone et al. 2007) and (2) that individuals with ASD exhibit superior processing of local visual information, such as in the embedded figure task (e.g., Jolliffe and Baron-Cohen 1997; Shah and Frith 1983), whereas they show inferior performance on tasks that require global (i.e., more holistic) visual information (e.g., Behrmann et al. 2006; Rondan and Deruelle 2007, see Happé and Frith 2006, for a review). As we have previously suggested (McCleery et al. 2009), it is possible that ASD is associated with an early propensity for processing objects, which is at the expense of processing faces properly. Whether there is a link between enhanced object processing and inferior face processing in ASD has yet to be tested to our knowledge. Additional analyses of the current data did not reveal any significant negative correlations between object and face sensitivity, but we likely did not have enough power to reveal an effect. Future studies with larger sample sizes will be needed to address this possibility.

In sum, the current study suggests that face discrimination sensitivity in adolescents with ASD may be fairly typical, whereas object discrimination sensitivity appears enhanced. In addition, there appear to be differential effects of age and IQ on face and object sensitivity in ASD. That is, higher IQs appear to correspond with better face sensitivity, whereas object sensitivity improves with age. By contrast, in typical development, face sensitivity (and perhaps object sensitivity) improves with age, but neither face nor object sensitivity appears to be tied to IQ. And finally, the development of inversion effects in ASD may be protracted. Together, the results of the current study suggest that individuals with ASD follow a qualitatively different path in the development of face and object processing abilities.

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Conflict of interest The authors declare that they have no conflict of interest.

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