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Atypical development of face and greeble recognition in autism

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Background: Impaired face processing is a widely documented deficit in autism. Although the origin of this deficit is unclear, several groups have suggested that a lack of perceptual expertise is contributory. We investigated whether individuals with autism develop expertise in visuoperceptual processing of faces and whether any deficiency in such processing is specific to faces, or extends to other objects, too. **Method:** Participants performed perceptual discrimination tasks, including a face inversion task and a classification-level task, which requires especially fine-grained discriminations, on three classes of stimuli: socially-laden faces, perceptually homogenous novel objects, greebles, and perceptually heterogeneous common objects. **Results:** We found that children with autism develop typical levels of expertise for recognition of common objects. However, they evince poorer recognition for perceptually homogenous objects, including faces and, most especially, greebles. **Conclusions:** Documenting the atypical recognition abilities for greebles in children with autism has provided an important insight into the potential origin of the relatively poor face recognition skills. Our findings suggest that, throughout development, individuals with autism have a generalized deficit in visuoperceptual processing that may interfere with their ability to undertake configural processing, and that this, in turn, adversely impacts their recognition of within-class perceptually homogenous objects. **Keywords:** Autism, visual processing, configural processing, face recognition, greebles, perceptual development, expertise, adolescence, child development, cognition. **Abbreviations:** FIE: face inversion effect; HFA: high-functioning individuals with autism; TD: typically-developing.

Impairments in face processing are a relatively recent discovery in autism, but have quickly become a widely accepted aspect of the behavioral profile. The impairment involves difficulty remembering faces (Boucher & Lewis, 1992), processing facial expressions (Ashwin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, 2007), and knowing which components of faces convey especially important communicative information (Joseph & Tanaka, 2003). Despite the growing empirical evidence, the origin of the face processing deficits in autism remains unknown.

One view suggests that individuals with autism have decreased motivation to attend to social stimuli, which limits the ability to gain expertise in face processing (Dawson et al., 2002; Grelotti, Gauthier, & Schultz, 2002). This social motivation impairment should not affect the recognition of non-social objects. Another view proposes that the face-processing deficits result from atypical perceptual processing (e.g., enhanced processing of local features; Happé & Frith, 2006; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006), which may limit the ability to develop expertise with *any class* of visual objects (Behrmann et al., 2006a; Behrmann, Thomas, & Humphreys, 2006b). This failure to develop expertise disproportionately impacts processing of perceptually homogenous objects since fine-grained discrimination and representation of the subtle metric variations between the constituent features, also called the *configural properties* of these stimuli (Diamond & Carey, 1986), are necessarily required to differentiate these similar objects. Faces are a paradigmatic example of this class of objects and the bias to focus on local features may impede the processing of the relational properties needed for individuating faces. Similarly, the failure to derive relational properties of the input may adversely impact other perceptually similar non-face objects.

To distinguish between these two potential origins of the face-processing deficit in autism, we evaluated whether individuals with autism have difficulty developing perceptual expertise and whether any such decrement is specific to faces or extends to other objects. We employed two empirical definitions of visuoperceptual expertise. First, we evaluated children's and adults' sensitivity to face inversion: typically-developing (TD) children and adults are slower and less accurate to recognize an inverted face (Valentine, 1988; Yin, 1969). Sensitivity to inversion is considered a measure of visuoperceptual expertise (Carey & Diamond, 1977) because: 1) the magnitude of the face inversion effect (FIE) increases with age, resulting from increasing knowledge about the spatial-relational properties of faces (see Carey, 1981); 2) it is evident in experts recognizing other

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objects of expertise (e.g., dogs for dog experts; Diamond & Carey, 1986) and in adults trained to recognize a novel class of objects (Gauthier & Tarr, 1997), and 3) it is less evident for other classes of objects that are not typically recognized at the individual level (Diamond & Carey, 1986; Yin, 1969).

The existing findings concerning whether individuals with autism show an intact FIE are disparate. Several studies have reported the absence of a FIE and superior performance on inverted face recognition in children and adolescents with autism compared to TD individuals (Hobson, Ouston, & Lee, 1988; Langdell, 1978; McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; Tantam, Monaghan, Nicholson, & Stirling, 1989). Other studies have found evidence for a spared FIE in children and adolescents with autism (Joseph & Tanaka, 2003; Lahaie et al., 2006; Rutherford, Clements, & Sekuler, 2007; Teunisse & de Gelder, 2003). Part of the discrepancy in these findings may be related to the inclusion of individuals spanning a broad range of ages, which may have masked the ability to observe developmental changes in the FIE, and/or the use of stimuli in which simultaneous changes in orientation and facial expression are present. To circumvent these potential confounds, we used naturalistic faces with neutral expressions to evaluate the FIE from childhood (ages 8–13) to adulthood in relatively high-functioning individuals with autism (HFA) and age-matched TD participants.

Our second measure of face expertise, previously used to evaluate deficits in expert face and object recognition in adults with acquired visual agnosia (Gauthier, Behrmann, & Tarr, 1999), involved manipulating the level of categorization at which faces are recognized. Most objects are recognized at the 'basic' level of abstraction (e.g., dog versus chair) and can be distinguished by unique features or configurations of features (Rosch 1978; Tanaka & Taylor, 1991). However, all objects can be recognized at increasingly more 'subordinate' levels (e.g., cocker spaniel versus poodle) and ultimately at the 'individual' level (e.g., poodle 1 versus poodle 2), where all exemplars share similar parts in a similar basic configuration but differ in the spatial relations within this basic configuration. At this last level, sensitivity to configural information is critical for discriminating individuals (Diamond & Carey, 1986). Expertise with any particular object class is indicated by the ability to recognize objects equally fast at the individual level (e.g., Joey's face), where featural differences are less diagnostic than configural properties for recognition, and at the basic level, where featural differences are very discriminating (Gauthier et al., 1999).

Recent studies of adults with autism suggest that the ability to recognize faces at the individual level is disproportionately slower than at the basic level, indicating a lack of expertise (Behrmann et al., 2006a). Interestingly, this difficulty was not limited to faces; in fact, adults with autism showed similar difficulties in discriminating perceptually homogenous novel objects at the individual level, indicating that atypical face processing may be related to a more general abnormality in visuoperceptual processing.

In the current study, in addition to evaluating the development of expert face recognition, we also investigated age-related changes in recognition abilities for common objects that are perceptually heterogeneous and for a novel class of perceptually homogenous objects, greebles, which were not imbued with any social information. Comparing face and common object recognition allowed us to evaluate the contribution of perceptual homogeneity to recognition deficits (although common objects are also less laden with social information than are faces). Since greebles are not objects of expertise for any of our participants, comparing face and greeble recognition provided us with a unique opportunity to evaluate the role of prior experience and social information-processing on recognition of perceptually homogenous objects. If autism is characterized by a developmental limitation in visuoperceptual processing that interferes with the ability to discriminate perceptually homogenous objects (regardless of whether they are imbued with social information), individuals with HFA will show atypical greeble recognition. If, however, the impairment in face processing is primarily due to the social nature of faces, individuals with autism should show typical greeble recognition abilities.

Method

Participants

The participants included 30 high-functioning (IQ > 80) individuals with autism (HFA: 15 children, 15 adults) and 30 age-matched TD participants. Fifteen of the HFA children and 12 of the TD children were male. In the adult sample, 13 of the HFA adults and 14 of the TD adults were male. Table 1 provides the demographic characteristics of the participants.

Participants and/or their legal guardians provided informed consent prior to participating in the study. All the experimental procedures complied with the Code of Ethics of the World Medical Association (1964 Declaration of Helsinki) and the standards of the University of Pittsburgh Internal Review Board.

All participants in the HFA group met criteria for autism for the social, communicative and total scores on the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 2001) and all domains on the Autism Diagnostic Interview (ADI & ADI Revised; Lord, Rutter, & Le Couteur, 1994), including age of onset. The diagnosis was also confirmed by expert clinical opinion (Minshew, 1996). The individuals with HFA, recruited from autism conferences and parent support groups, were medically healthy and had no identifiable genetic, metabolic, or infectious etiology for their disorder. Participants were also free of birth or

Table 1 Demographic characteristics of typically-developing (TD) and high-functioning autism (HFA) participants

	Age	VIQ	PIQ	FSIQ	ADOS Social	ADOS Communication	ADOS Total
Children (8–13)							
HFA	11(1)	99(16)	105(17)	102(15)	10(2)	4(1)	14(3)
TD	12(1)	104(9)	103(7)	104(7)			
Adults (>18)							
HFA	32(13)**	97(18)*	106(14)	103(16)	10(2)	5(1)	15(2)
TD	22(5)	109(10)	112(10)	111(10)			

Note: Cells contain mean scores and (SD), ** $p < .01$, * $p < .05$.

traumatic brain injury, seizures, attention deficit disorder, and depression. Their personal and family health histories were evaluated in the initial screening interview and in the medical review portion of the ADI. IQ was determined for all participants using the Wechsler Abbreviated Scale of Intelligence.

TD adults were recruited through advertisements posted on the web, in newspapers, and on local community bulletin boards. Children were recruited via advertisements given to them at school to take home to their parents. TD participants were selected to match the HFA group on age, Full Scale IQ, sex, and socioeconomic status of the family of origin. TD participants were included if they were medically healthy, free of regular medication usage, and had good peer relationships as determined by parent, self-report, and staff observations during the screening procedures. TD participants were excluded if they or their first-degree relatives had a history of autism, neurological or psychiatric illness, acquired brain injury, learning disabilities, developmental delay, school problems, substance abuse, or medical disorders with central nervous system implications. A single episode of depression in a parent during a stressful episode was not considered grounds for exclusion providing no other family members reported depressive episodes.

Procedure

General procedure. The experiments were conducted on a laptop using E-Prime software (Schneider, Eschman, & Zuccolotto, 2001) in a dimly lit room with a viewing distance of approximately 60 cm from the screen. Participants performed a forced-choice recognition task adapted from Sangrigoli and de Schonen (2004) in separate blocks for each object category, the order of which was counterbalanced across participants in each age group. In each trial, a target stimulus was displayed centrally for 250 milliseconds, followed by a 1000-millisecond delay, and finally followed by a choice screen in which the target and a distracter were displayed. Participants pressed a designated key on the left or right to indicate whether the target was on the left or right side of the screen. The target position was counterbalanced across trials. The inter-trial interval was 1000 milliseconds. Participants were instructed to respond as quickly and as accurately as possible and completed six practice trials before each block. To provide all participants the maximal opportunity for correct discrimination, an unlimited amount of time to respond was provided. Testing sessions lasted approximately 45–60 minutes and participants were given the opportunity to take a 5-minute break following each block.

Stimuli

The face stimuli consisted of color pictures of male and female faces provided by the Max-Planck Institute for Biological Cybernetics in Tübingen, Germany (see Figure 1). The novel object stimulus set consisted of color pictures of greebles (Gauthier & Tarr, 1997; Gauthier et al., 1999), which have four protruding parts organized in approximately the same spatial configuration on a vertically oriented central part (see Figure 3). The 'gender' difference is defined by the orientation of the parts, either all pointing upward or downward. Each greeble is unique within the set. The common objects consisted of gray-scale pictures (see Figure 4) used in previous studies (Gauthier et al., 1999), and were created by rendering 3D object models using Silicon Graphics Inventor software. They included inanimate objects like flowers, furniture, glasses, vegetables, vehicles, and clocks.

Sixty items from each object category were used for the experimental trials and an additional set of six items was used during the practice trials. Within each block, each stimulus was used twice as a target and twice as a distracter, creating 30 trials for each condition in each object category, which were randomized throughout the block of trials.

Face inversion procedure

Participants performed separate blocks of upright and inverted trials. The target and the choice stimuli were presented in the upright orientation in the former and in the inverted orientation in the latter. Participants always performed the upright trials first to maximize the possibility that participants with HFA would initially approach the task in an ecologically valid way prior to having to confront less naturally occurring inverted faces. This manner of ordering the experiment is standard so as not to 'contaminate' the upright condition.

Category-level procedure

For all three classes of objects, the individual/exemplar level included perceptually homogenous targets, which required the most fine-grained discriminations.

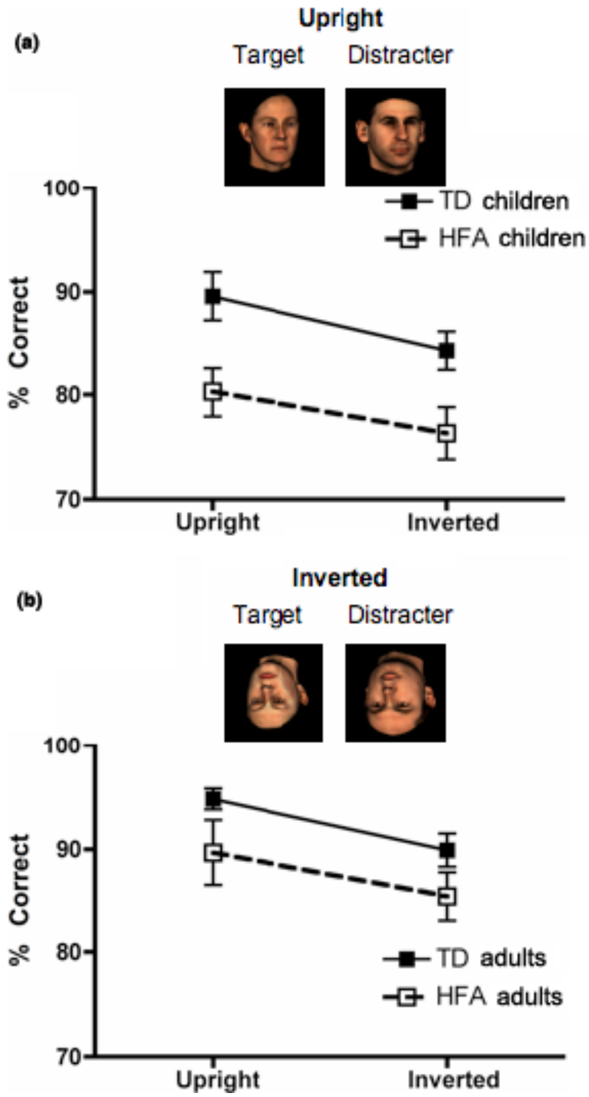

Figure 1 Examples of upright and inverted face stimuli and developmental differences in sensitivity to face inversion plotted as mean accuracy and as a function of experimental group in a) children and b) adults

The gender (faces and greebles)/subordinate (objects) level included items that were less homogenous and more easily discriminated on the basis of featural differences.

Data analyses

Accuracy was measured as the proportion of correct items within each block. Reaction times (RT), measured from the onset of the stimulus choice screen, for correct trials only were analyzed. Differences across orientation, category level, age, and experimental group were investigated using repeated-measures ANOVAs with the factors of orientation (upright, inverted) or category level (gender/subordinate, individual/exemplar), age (children, adults), and experimental group (TD, HFA). Effect sizes are reported as Partial Eta^2.

Results

Face inversion

Preliminary analyses of RT differences for the FIE revealed that RT was insensitive ($F < 1$) to developmental differences in both the TD and HFA groups. This is consistent with previous findings showing that under conditions of limited exposure to a target stimulus, such as that used in this forced-recognition paradigm, accuracy may be a more sensitive measure (Massaro, 1989). Also, even in simple manual tasks, RT changes drastically throughout childhood in TD populations (Fry & Hale, 1996). RT remains slower and more variable in individuals with autism in adolescence (Inui & Suzuki, 1998) when it begins to stabilize in TD individuals. Finally, since only correct trials were analyzed for RT differences, there were large differences across age and experimental groups in the number of trials that contributed to the RT analyses. These factors contributed to large variability both within and between participants. Consequently, only findings from the accuracy analyses are presented.

Figure 1 shows the mean accuracy for both upright and inverted faces as a function of age and experimental group. There was a main effect of age, $F(1, 56) = 14.6$, $p < .001$, $\eta_p^2 = .21$: children were less accurate than adults. Also, the HFA group was less accurate than the TD group, $F(1, 56) = 12.3$, $p < .001$, $\eta_p^2 = .18$, and there was no age × experimental group interaction. This accuracy difference between the TD and HFA groups was not related to the differences in VIQ, $r(29) = .26$, p = n.s., or age, $r(29) = -.10$, p = n.s., between the TD and HFA adults. Both TD and HFA groups showed a pervasive FIE, $F(1, 56) = 17.1$, $p < .001$, $\eta_p^2 = .23$, with lower accuracy for inverted ($M = 84.0\%$, $SD = 9.4\%$) than upright faces ($M = 88.6\%$, $SD = 10.2\%$). There were no significant interactions between age, experimental group, and orientation.

Having demonstrated sensitivity to inversion in the autism group, even in the children, we now examine the performance of the participants when category level was manipulated during recognition of faces, greebles, and common objects.

Category level

Figures 2–4 show the mean accuracy for both gender/subordinate and individual/exemplar trials plotted as a function of object, age, and experimental group. There was a main effect of group, with lower accuracy for the HFA than TD group, $F(1, 56) = 10.1$, $p < .005$, $\eta_p^2 = .15$. However, this difference was qualified by the category of the object, $F(1, 56) = 3.6$, $p < .05$, $\eta_p^2 = .06$. Separate repeated-measures ANOVAs within each experimental group revealed that only the HFA group was disproportionately less

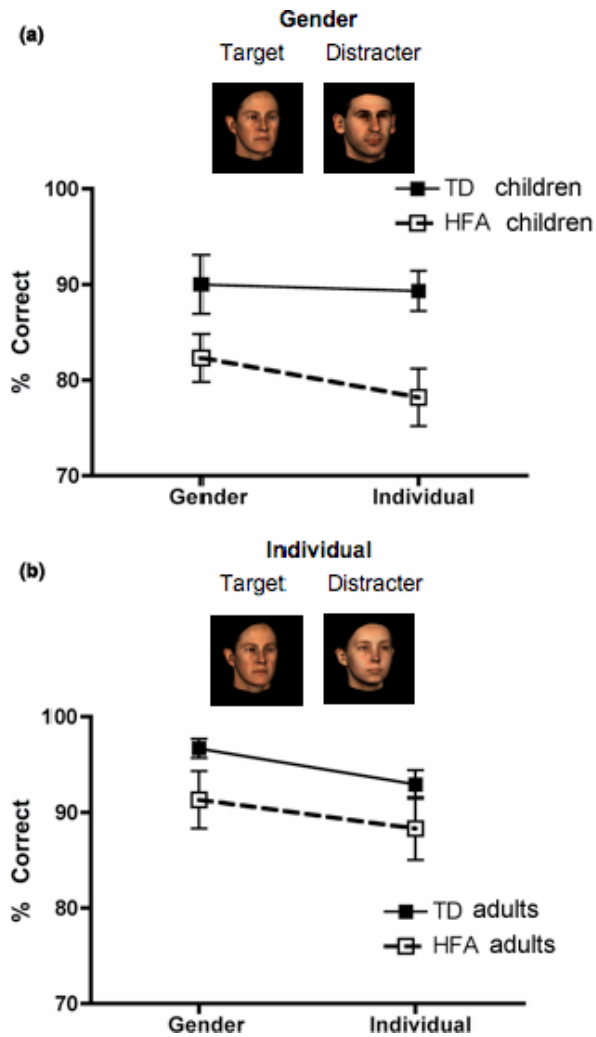

Figure 2 Examples of individual and gender discrimination trials during face recognition and developmental differences in sensitivity to the kind of discrimination plotted as mean accuracy (±1 SEM) and as a function of experimental group in a) children and b) adults

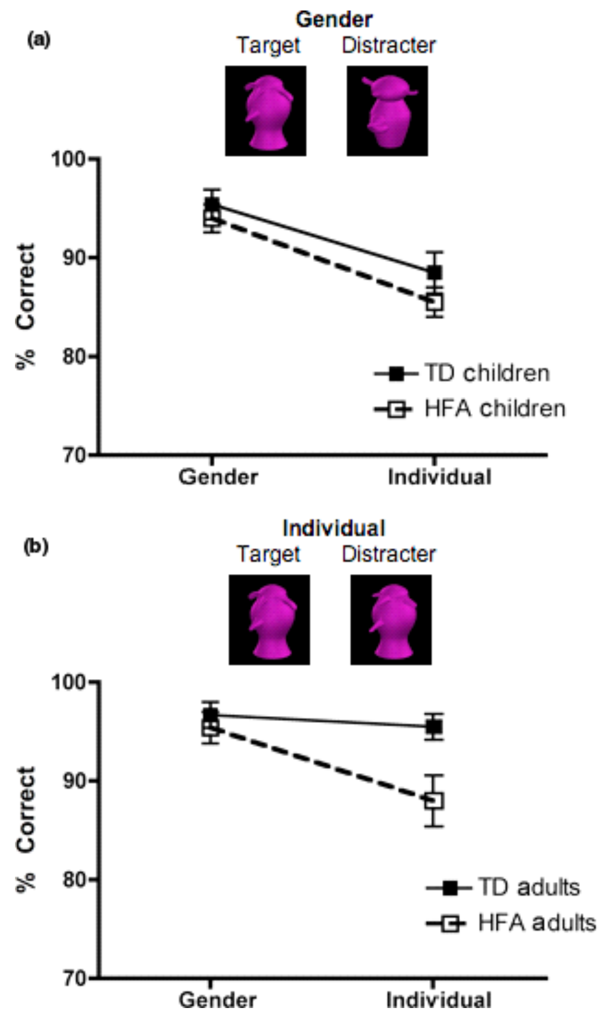

Figure 3 Examples of individual and gender discrimination trials during greeble recognition and developmental differences in sensitivity to the kind of discrimination plotted as mean accuracy (±1 SEM) and as a function of experimental group in a) children and b) adults

accurate depending on the object category, $F(2, 56) = 11.4$, $p < .001$, $\eta_p^2 = .29$. Bonferroni corrected post-hoc comparisons revealed that the HFA group was less accurate on faces compared to greebles, $p < .005$, and common objects, $p < .002$, but that greebles and common objects were equally accurate overall.

There was a main effect of category level, $F(1, 56) = 84.9$, $p < .001$, $\eta_p^2 = .60$, but this effect was qualified by age, object, and experimental group. There were significant object × category level, $F(2, 112) = 7.0$, $p < .001$, $\eta_p^2 = .11$, and object × category level × age group, $F(2, 112) = 4.0$, $p < .025$, $\eta_p^2 = .07$, interactions and a trend for an experimental group × category level interaction, $F(1, 56) = 3.7$, $p < .06$, $\eta_p^2 = .06$. To interpret these interactions, separate analyses were performed within each object category.

Face task

In the face task, children (M = 84.9%, SD = 10.1%) were less accurate than adults (M = 92.3%, SD = 9.0%), $F(1, 56) = 10.2$, $p < .005$, $\eta_p^2 = .16$. The HFA group (M = 85.0%, SD = 11.5%) was less accurate than the TD group (M = 92.2%, SD = 7.2%), $F(1, 56) = 9.7$, $p < .005$, $\eta_p^2 = .15$, and individual discriminations (M = 87.2%, SD = 11.1%) were more difficult than gender discriminations (M = 90.1%, SD = 10.9%), $F(1, 56) = 7.2$, $p < .01$, $\eta_p^2 = .11$ (see Figure 2). There were no interactions.

Greeble task

In the greeble task, children (M = 90.7%, SD = 5.7%) were less accurate than adults (M = 93.8%, SD = 6.4%), $F(1, 56) = 4.0$, $p < .05$, $\eta_p^2 = .07$, the

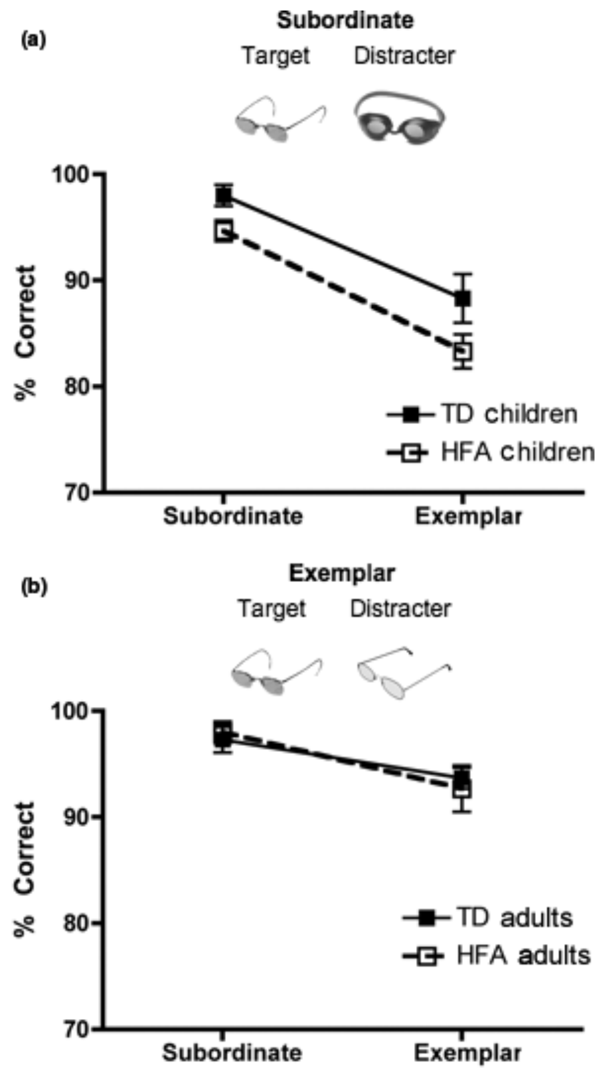

Figure 4 Examples of exemplar and subordinate discrimination trials during common object recognition and developmental differences in sensitivity to kind of discrimination plotted as mean accuracy (±1 SEM) and as a function of experimental group in a) children and b) adults

HFA group was less accurate ($M = 90.7\%$, $SD = 6.1\%$) than the TD group ($M = 93.8\%$, $SD = 6.0\%$), $F(1, 56) = 4.6$, $p < .05$, $\eta_p^2 = .08$, and individual ($M = 89.4\%$, $SD = 8.3\%$) discriminations were more difficult than gender discriminations ($M = 95.4\%$, $SD = 5.6\%$), $F(1, 56) = 59.2$, $p < .001$, $\eta_p^2 = .51$ (see Figure 3). However, there were also category level × experimental group, $F(1, 56) = 6.1$, $p < .025$, $\eta_p^2 = .10$, and category level × age group, $F(1, 56) = 4.7$, $p < .05$, $\eta_p^2 = .08$, interactions. There was no category level × age group × experimental group interaction, $F(1, 56) = 2.1$, p = n.s.

Separate analyses of the category level effect within each age and experimental group revealed that, in the TD group, both children and adults were less accurate to make individual (children: $M = 88.5\%$, $SD = 8.1\%$; adults: $M = 95.5\%$, $SD = 5.1\%$) than gender discriminations (children: $M = 95.4\%$, $SD = 5.8\%$; adults: $M = 96.7\%$, $SD = 5.0\%$), $F(1, 28) = 26.1$, $p < .001$, $\eta_p^2 = .48$. However, there was also a category level × age group interaction, $F(1, 28) = 12.4$, $p < .001$, $\eta_p^2 = .31$. Planned comparisons revealed that the children and adults performed similarly on gender trials, $t(28) = .7$, p = n.s., one-tailed, but that adults were more accurate on individual trials, $t(28) = 2.8$, $p < .001$, one-tailed. In the HFA group, there was only a main effect of category level, $F(1, 28) = 35.0$, $p < .001$, $\eta_p^2 = .56$, but no condition × age group interaction, $F(1, 28) = .18$, $p <$ n.s.

Among the children, both groups were equally accurate, $F(1, 28) = 1.1$, p = n.s., and similarly less accurate on individual compared to gender discriminations, $F(1, 28) = 53.4$, $p < .001$, $\eta_p^2 = .66$; there was no category level × group interaction, $F(1, 28) = .6$, p = n.s. Contrary to the children, HFA adults tended to be less accurate than TD adults, $F(1, 28) = 3.8$, $p = .06$, $\eta_p^2 = .12$. Both groups of adults were less accurate on individual compared to gender discriminations, $F(1, 28) = 14.0$, $p < .001$, $\eta_p^2 = .33$; however, HFA adults were disproportionately less accurate on individual trials, $F(1, 28) = 7.0$, $p < .025$, $\eta_p^2 = .20$.

To investigate the age-related effects on greeble recognition in a more continuous way, separate Pearson product–moment correlations were conducted between age and the magnitude of the category level effect (e.g., gender–individual) for each age group in the TD and HFA groups. Even in the small age range from 8 to 13 years of age, children in the TD group exhibited a significant decrease in the category level effects with age, $r(15) = -.63$, $p < .01$, two-tailed. On the other hand, there was no relation between age and the category level effect in the HFA children, $r(15) = -.15$, p = n.s., or HFA adults, $r(15) = -.12$, p = n.s. The TD adults also exhibited a decrease in the magnitude of the category level effect during greeble recognition, $r(15) = -.70$, $p < .01$, two-tailed; however, this effect was driven by the oldest adult who happened to be more accurate on individual compared to gender level trials. When this participant was removed from the analysis the effect was no longer significant, $r(14) = .06$, p = n.s. These results indicate that even though there were no group differences in greeble performance between the TD and HFA children (as indicated in the ANOVA results), in fact, TD children did show improvements with age on greeble recognition, whereas HFA children did not.

Finally, since the adults groups differed on age and verbal IQ, Pearson product–moment correlations were conducted between these factors and accuracy. There was no significant relationship between age and accuracy, $r(29) = -.02$, p = n.s., or verbal IQ and accuracy, $r(29) = .30$, p = n.s.

Common objects task

As in the other tasks, on common object recognition, children (M = 91.3%, SD = 5.1%) were less accurate than adults (M = 95.4%, SD = 4.5%), $F(1, 56) = 13.1$, $p < .001$, $\eta_p^2 = .19$. Unlike in the face and greeble tasks, the HFA group (M = 92.3%, SD = 5.7%) was equally accurate compared to the TD group (M = 94.5%, SD = 4.5%), $F < 1$. Exemplar (M = 89.5%, SD = 8.1%) discriminations were more difficult than subordinate discriminations (M = 97.0%, SD = 4.1%), $F(1, 56) = 68.9$, $p < .001$, $\eta_p^2 = .55$ (see Figure 4). There were no interactions between experimental group and category level. However, there was a category level × age group interaction, $F(1, 56) = 11.02$, $p < .005$, $\eta_p^2 = .16$. Analyses within each age group revealed that children in both the TD and HFA groups were less accurate for exemplar than subordinate discriminations, $F(1, 28) = 58.0$, $p < .001$, $\eta_p^2 = .67$. There was no category level × group interaction, but HFA children were less accurate than TD children during common object recognition, $F(1, 28) = 5.9$, $p < .025$, $\eta_p^2 = .18$. Similarly, both TD and HFA adults were similarly affected by the level of discrimination and were less accurate on exemplar than subordinate trials, $F(1, 28) = 14.8$, $p < .001$, $\eta_p^2 = .35$. No other effects or interactions were significant.

Discussion

The goals of these studies were to evaluate whether 1) individuals with autism demonstrate atypical development of face expertise, and 2) any observed perceptual alteration is unique to faces or extends more generally to other classes of visual objects. With respect to our first goal, we found that individuals with autism do develop some form of visuoperceptual expertise for faces. By the age of 11, children and adults with autism do show the classic face inversion effect, consistent with four other studies of face inversion in children and adolescents with autism (Joseph & Tanaka, 2003; Lahaie et al., 2006; Rutherford et al., 2007; Teunisse & de Gelder, 2003). Also, they are not disproportionately more affected when making individual compared to gender-level discriminations as one might have expected given our previous results in a separate group of adults with autism (Behrmann et al., 2006a). However, they are significantly less accurate than the TD group, overall, in judging the perceptual similarity of novel faces. These results suggest that both children and adults with autism do reveal some visuoperceptual expertise for faces (by late childhood) but are, in general, less skilled at discriminating and recognizing faces than are TD individuals. In fact, across all object categories, the HFA group showed the largest deficit in face recognition (as indicated by the effect sizes of the main effect of group), despite their relative expertise.

One possible explanation for this interesting pattern of results is that perceptual expertise for faces is spatially restricted in autism, which limits the ability to make the most fine-grained discriminations between faces. For example, there are several reports that individuals with autism afford unusual significance to the mouth region of a face and are markedly deficient when recognition depends on the eyes (Dawson, Webb, & McPartland, 2005; Joseph & Tanaka, 2003; Baron-Cohen, Wheelwright, & Joliffe, 1997). Perceptual expertise for faces may be spatially restricted to the lower half of the face in autism, which could support adequate recognition when the mouth region is distinctive but may not be sufficient to support recognition of faces that primarily differ in their configural properties, particularly involving the eye region. A similar argument has been made about individuals with prosopagnosia who suffer from a loss of, or reduced access to, previously acquired perceptual expertise with faces (Bukach, Bub, Gauthier, & Tarr, 2006). Additional studies investigating the development of visuoperceptual expertise for faces in the lower and upper half of faces are needed to evaluate this explanation.

Also, although TD and HFA children exhibited similar degrees of visuoperceptual expertise for faces, it is still possible that the developmental trajectory for the acquisition of this expertise is different in autism. For example, TD children might acquire such expertise sooner than HFA children. Additional longitudinal experiments beginning in early childhood will help evaluate this possibility.

With regard to our second goal, our most striking finding is that atypical perceptual processing in individuals with autism is observable during novel object recognition, but only if the objects are perceptually homogenous. As a group, individuals with HFA were also less accurate when recognizing greebles, a novel set of perceptually homogeneous objects, although not as severely as during face recognition (see effect sizes). More importantly, the HFA group was disproportionately impaired when attempting to make individual discriminations among the greebles. Furthermore, the HFA group did not exhibit an age-related improvement in greeble processing, as did the TD group. Overall, children in both groups were similarly less accurate when making individual compared to gender-level discriminations. However, upon closer examination, with age TD children were becoming better at these individual-level discriminations (as indicated by the correlations between age and the magnitude of the category-level effect). Also, TD adults were much less affected by the level of the discrimination than were HFA adults. HFA children did not get better at individual-level discriminations with age. This age-related improvement in greeble processing in the TD group, but not the HFA group, indicates a limited ability to develop recognition skills for perceptually homogenous objects that need to be identified at the individual level. Although this finding has been previously reported in adults with autism (Behrmann et al., 2006a), this is the first study to demonstrate that visuoperceptual processing of a novel class of perceptually homogenous objects is developmentally impaired in autism.

These findings may seem at odds with existing reports that children with autism can develop special interests (and quite good recognition) for novel objects, like cartoon characters (Grelotti et al., 2005). One might argue that our findings of developmental differences in greeble recognition were not related to a visuoperceptual deficit per se, but to a lack of interest on the part of the autism group. There are two reasons to believe that this may not be the case. First, greebles were designed to be perceptually homogenous. They share the same body and appendage configuration and color. Cartoon characters, stamps, and coins (common objects of special interest in autism) are more perceptually heterogeneous like common objects, in that featural differences may be very diagnostic for discriminating them from one another. Individuals with autism are quite good at discriminating heterogeneous common objects using these featural differences (Boucher & Lewis, 1992; Hauck, Fein, Maltby, Waterhouse, & Feinstein, 1998; Teunisse & de Gelder, 2003; Trepagnier, Sebrechts, & Peterson, 2002). Second, since greebles are cartoon-like and not social in nature, we expected that social aversion would not interfere with greeble recognition in the autism group. However, they evinced *more difficulty* discriminating the most perceptually similar greebles. In fact, the cost in accuracy for individual compared to gender level greeble discriminations was more than twice that for face discriminations in the HFA group. This suggests that it is perceptual homogeneity that makes discriminations particularly difficult for individuals with autism.

This interpretation is supported by our findings that children and adults with autism performed similarly to TD children and adults in the common objects task. Although the magnitude of sensitivity to the category-level manipulation was similar in the common objects and greeble tasks across both the TD and HFA groups (see effect sizes), unlike in the greeble findings, both groups exhibited age-related *improvements* in the ability to discriminate common objects at the individual level. These findings are consistent with several other studies that have found equivalent or even superior performance on building and object recognition in children and adolescents with autism (Boucher & Lewis, 1992; Hauck et al., 1998; Teunisse & de Gelder, 2003; Trepagnier et al., 2002). It is possible that both the TD and HFA groups showed similar age-related changes in common object recognition because it was an easier task, since common objects, even at the exemplar level, have featural differences that may be especially discriminating. Even though participants were more accurate during the object recognition task, the relative cost in accuracy when making the individual discriminations was comparable to that in the greeble tasks, as indicated by the similar effect sizes, and many times larger than that in the faces task. Importantly, this cost in performance on individual-level trials was consistent across both the TD and HFA groups in the common objects task, but not in the perceptually homogenous greebles task. Together, these results indicate that greebles placed additional demands on the visuoperceptual system for recognition in the HFA group.

Comparing recognition abilities for faces and for greebles in children with autism has provided novel insight into the potential origin of the relatively poor face recognition skills that are so widely cited. These results suggest that even if a social aversion to faces contributes to limitations in the development of face expertise in autism, it may not be the primary factor since processing of other non-social objects, specifically perceptually homogenous objects, is also affected. Greebles are novel objects that are essentially devoid of socially-laden information in this paradigm and there is no obvious reason why individuals with autism would have an inherent social aversion to these stimuli that would interfere with their ability to process them. Also, even though the greebles were novel and not objects of expertise for any of the participants, there were still impressive differences between the TD and HFA groups in the ability to discriminate greebles (as indicated by the finding that this was the only object category for which there was a significant group × category level interaction). This was especially true at the individual-level discrimination, which requires sensitivity to spatial-relational properties of the greebles, even in novices.

Our results, which reveal more obvious difficulties in greeble than face processing throughout development, may indicate that individuals with autism develop compensatory strategies for face processing over many years of experience, which may mask underlying visuoperceptual abnormalities. In other words, trying to evaluate visuoperceptual expertise using face stimuli may lead one to overestimate the abilities of individuals with autism. As mentioned above, it is possible that individuals with autism may be able to acquire some visuoperceptual expertise but only for a spatially restricted part of faces, due to their lack of interest, aversion, or attentional bias away from the eye region of the face. Also, several studies have reported that individuals with autism are biased to attend to the individual features of a face (Joseph & Tanaka, 2003; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Lahaie et al., 2006), which may result from superior perceptual processing of local or featural information for all classes of visual stimuli (Behrmann et al., 2006a; Happé & Frith, 2006; Mottron et al., 2006). This superior perceptual processing of facial features over many years of experience may facilitate recognition for faces with particularly distinctive features, but may also mask the extent of the atypical visuoperceptual processing for faces. As a result, evaluating visuoperceptual processing for a novel class of stimuli may provide a truer test of their abilities. In fact, our findings of atypical greeble recognition in the HFA group, even in adulthood, are not confounded by potential compensatory strategies and may be the strongest test of atypical visuoperceptual processing in autism.

In summary, our findings indicate that individuals with HFA do not exhibit perceptual difficulties that are unique to faces or primarily social in nature. Importantly, our findings suggest that individuals with autism exhibit a generalized deficit in fine-grained visuoperceptual processing, which exists throughout development and is most easily observed during recognition of novel objects that are not confounded by potential compensatory strategies. This visuoperceptual processing abnormality may interfere with the ability to do configural processing and, as a result, is most evident for classes of perceptually homogenous objects, with faces being the paradigmatic and most critical example of such a class.

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