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Atypical Development of Face and Greeble Recognition in Autism

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Abstract

BACKGROUND—Impaired face processing is a widely cited deficit in autism, and, 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 visuo-perceptual processing of faces and whether any decrement in such processing is specific to faces, or extends to other objects, too.

METHODS—Participants performed perceptual discrimination tasks, including a face inversion task and a classification-level task, which requires more-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 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 visuo-perceptual 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

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 goes beyond face recognition and involves difficulty in remembering faces (Boucher & Lewis, 1992), processing facial expressions (Ashwin, Baron-Cohen, Weelwright, O’Riordan, & Bullmore, 2006), and knowing which components of faces convey especially important communicative

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ABBREVIATIONS: HFA, TD, FIE

information (Joseph & Tanaka, 2003). Not surprisingly, these deficits contribute significantly to social dysfunction in autism.

Despite the growing empirical evidence, the origin of the face processing deficits in autism remains unknown. One view suggests that individuals with autism have a 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 face-processing deficits result from atypical perceptual processing (e.g. enhanced processing of local features; Happé & Frith, 2006; Motttron, Dawson, Soulieres, Hubert, & Burack, 2006), which limits 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), is required to differentiate these similar objects. Faces are a paradigmatic class of such objects and the bias to focus on local features may impede the processing of the relational properties needed for individuating faces and 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 adult's 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; Flin 1983); 2) it is evident in experts recognizing other 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, 1996), 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).

However, there are disparate findings about whether individuals with autism show an intact FIE. 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, et al., 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; Teunisse & de Gelder, 2003). Part of the discrepancy in these findings may be related to the inclusion of broad age ranges, which may have masked the ability to observe developmental changes in the FIE, heterogeneity of the sample (Barton et al., 2007) 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 typically-developing participants (TD).

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 more “subordinate” levels (e.g., cocker spaniel vs poodle), where all exemplars share similar parts in a similar basic configuration but differ in the spatial relations within this basic configuration. It is at this level that sensitivity to configural information is critical for making subordinate-level discriminations between exemplars (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 common and novel objects at the individual levels, indicating that atypical face processing may be related to a more general abnormality in visuoperceptual processing. In the current study, we evaluated the developmental trajectory of the ability to discriminate faces, homogeneous novel objects known as Greebles, and common objects at the individual level in HFA and TD children and adults.

Methods

Participants

The participants included 30 relatively high-functioning 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, & LeCouteur, 1994). 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 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 participants were community volunteers matched to the HFA group on age, Full Scale IQ, sex, and socioeconomic status. TD participants were included if they were in medically healthy, free of regular medication usage, and had good peer relationships as determined by parent, self-report and staff observations. 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 & de Schonen (2004). 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 avoid underestimating participants' abilities to discriminate the stimuli, an unlimited amount of time to respond was provided.

Stimuli—The face stimuli consisted of color pictures of male and female faces provided by the Max-Planck Institute for Biological Cybernetics in Tuebingen, 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.

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.

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.

Categorization Level Procedure—For all three classes of objects, the individual or exemplar condition included perceptually homogenous targets, which required the most fine-grained discriminations. The gender (faces and Greebles) and subordinate (objects) conditions included items that were less homogenous and more easily discriminated on the basis of featural differences. There were an equal number of individual and gender/subordinate trials for each kind of object, which were randomized throughout the block of trials. The order of presentation of the face, common object, and novel object blocks was counterbalanced.

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, categorization level, age, and experimental group were investigated using repeated-measures ANOVAs with the factors of orientation (upright, inverted) or classification level (gender/subordinate, individual/exemplar), age (children, adults), and experimental group (TD, HFA).

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 that under conditions of limited exposure of 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) and remains slower and more variable in individuals with autism in adolescence (Inui & Suzuki, 1998) when it begins to stabilize in typical 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 groups. There was a main effect of age, $F(1, 56) = 14.6, p < .001$: children were less accurate than adults. Also, the HFA group was less accurate than the TD group, $F(1, 56) = 12.3, p < .001$, and there was no age $\times$ experimental group interaction. This accuracy difference between the TD and HFA groups was not related to the differences in VIQ, $r(29) = 0.26, p = \text{n.s.}$, or age, $r(29) = -0.10, p = \text{n.s.}$, between the TD and HFA adults.

Both TD and HFA groups showed a pervasive FIE, $F(1, 56) = 17.1, p < .001$, 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 categorization level was manipulated and all three stimulus classes were used.

Categorization Level

Figures 2–4 show the mean accuracy for both gender and individual conditions plotted as a function of object category, age, and experimental group. There was a main effect of group, with lower accuracy for the HFA than TD group, $F(1, 56) = 10.1, p < .005$. However, this difference was qualified by the category of the object, $F(1, 56) = 3.6, p < .05$. Separate repeated-measures ANOVAs within each experimental group revealed that only the HFA group was disproportionately less accurate depending on the object category, $F(2, 58) = 11.2, p < .001$. 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 categorization level, $F(1, 56) = 84.9, p < .001$, but this effect was qualified by age, object category, and experimental group. There were significant condition $\times$ category, $F(2, 112) = 7.0, p < .001$, and condition $\times$ category $\times$ age group, $F(2, 112) = 4.0, p < .025$, interactions and a trend for an experimental group $\times$ condition interaction, $F(1, 56) = 3.7, p < .06$. 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 ($M = 92.3\%$, $SD = 9.0\%$), $F(1, 56) = 10.2$, $p < .005$. The HFA group ($M = 85.0\%$, $SD = 11.5\%$) was less accurate than the TD group ($M = 92.2\%$, $SD = 7.2\%$), $F(1, 56) = 9.7$, $p < .005$, and individual discriminations ($M = 87.2\%$, $SD = 11.1\%$) were more difficult than gender discriminations ($M = 90.1\%$, $SD = 10.9\%$), $F(1, 56) = 7.2$, $p < .01$ (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 ($M = 93.8\%$, $SD = 6.4\%$), $F(1, 56) = 4.0$, $p < .05$, the HFA group was less accurate ($M = 90.7\%$, $SD = 6.1\%$) than the TD group ($M = 93.8\%$, $SD = 6.0\%$), $F(1, 56) = 4.6$, $p < .05$, and individual ($M = 89.4\%$, $SD = 8.3\%$) discriminations were more difficult than gender discriminations ($M = 95.4\%$, $SD = 5.6\%$), $F(1, 56) = 59.2$, $p < .001$ (see Figure 3). However, there were also condition $\times$ experimental group, $F(1, 56) = 6.1$, $p < .025$, and condition $\times$ age group, $F(1, 56) = 4.7$, $p < .05$, interactions. The HFA group ($M = 8.0\%$, $SD = 7.3\%$) made more errors than the TD group ($M = 4.1\%$, $SD = 5.2\%$) when making individual discriminations, and this was also true for children ($M = 7.7\%$, $SD = 5.8\%$) compared to adults ($M = 4.3\%$, $SD = 7.0\%$). There was no condition $\times$ age group $\times$ experimental group interaction. Finally, Pearson product-moment correlations failed to identify significant relationships between age and accuracy, $r(29) = -0.02$, $p = \text{n.s.}$, or between verbal IQ and accuracy, $r(29) = 0.30$, $p = \text{n.s.}$, in the adult group.

Common Objects Task—As in the other tasks, on common object recognition, children ($M = 91.3\%$, $SD = 5.1\%$) were less accurate than adults ($M = 95.4\%$, $SD = 4.5\%$), $F(1, 56) = 13.1$, $p < .001$. 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 ($M = 97.0\%$, $SD = 4.1\%$), $F(1, 56) = 68.9$, $p < .001$ (see Figure 4). There were no interactions between experimental group and condition. However, there was a condition $\times$ age group interaction, $F(1, 56) = 11.02$, $p < .005$. Analyses within each age group revealed that children in both the TD and HFA groups were less accurate for exemplar than subordinate discriminations, $F(1, 28) = 58.0$, $p < .001$. There was no condition $\times$ group interaction, but HFA children were less accurate than TD children during common object recognition, $F(1, 28) = 5.9$, $p < .025$. Similarly, both TD and HFA adults were similarly affected by the level of discrimination and were less accurate on exemplar than subordinate trials, $F(1, 28) = 14.8$, $p < .001$. 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 not develop visuo-perceptual expertise with faces to the same degree as their typical counterparts (see also Barton et al., 2007). Children and adults with autism do show the classic face inversion effect, consistent with at least three other studies of face inversion in children and adolescents with autism (Joseph & Tanaka, 2003; Lahaie et al., 2006; Teunisse & de Gelder, 2003). However, they are significantly less accurate than the TD group in judging the perceptual similarity of novel faces. Interestingly, 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 who showed greater costs in reaction time at the individual compared to gender level than did age- and IQ-matched controls (Behrmann et al., 2006a). These results suggest that both children and adults with autism do reveal some form of visuo-perceptual expertise for face processing (as in the FIE task) but are, in fact,

less skilled at discriminating and recognizing faces (even in making simple gender differentiation between faces) than are age- and IQ-matched TD individuals.

With regard to our second goal, our most striking and novel finding is that the atypical perceptual profile in individuals with autism was not limited to faces, but extends to another class of perceptually homogenous objects, Greebles. As a group, individuals with HFA were less accurate when recognizing Greebles and were disproportionately impaired when attempting to make individual discriminations among the Greebles compared to the TD individuals. Although this finding has been previously reported in adults with autism (Behrmann et al., 2006), this is the first study to demonstrate that a deficit in visuo-perceptual processing of novel class of perceptually homogenous objects is impaired even in childhood.

Importantly, the perceptual deficit was not pervasive for all classes of objects, but was specific to perceptually homogenous objects. Children with HFA followed the same developmental trajectory as did TD children in the ability to recognize heterogeneous common objects. 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, Fein, Maltby, Waterhouse, & Feinstein, 1998; Teunisse & de Gelder, 2003; Trepagnier, Sebrechts, & Peterson, 2002).

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. First, our results are not consistent with the social motivation hypothesis for the origin of the face-processing deficits in autism. Greebles are novel objects that are essentially devoid of socially-laden information in this paradigm and it is not obvious 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 dramatic differences between the TD and HFA groups in the ability to discriminate Greebles. This was especially true at the individual-level discrimination, which requires sensitivity to spatial-relational properties of the Greebles, even in novices.

Second, our results, which reveal more obvious difficulties in Greeble than face processing recognition throughout development, may indicate that individuals with autism develop compensatory strategies for face processing over many years of experience, and that this may mask underlying visuo-perceptual abnormalities. In other words, trying to evaluate visuo-perceptual expertise using face stimuli may lead one to overestimate the abilities of individuals with autism. Rather, evaluating visuo-perceptual processing abilities for a novel class of stimuli, for which the individuals have no experience and, therefore, have not had the opportunity to develop compensatory strategies, may provide a truer test of their perceptual abilities. In fact, our findings of atypical visuo-perceptual processing of novel objects in the HFA group, even in adulthood, are not confounded by potential compensatory strategies and may be the strongest test of atypical visuo-perceptual 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 visuo-perceptual processing, which exists throughout development and is most easily observed during recognition of novel objects that are not confounded by potential compensatory strategies. This visuo-perceptual processing deficit may interfere with the ability to undertake 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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Appendix

Appendix – Results from all Statistical Comparisons

Task	Statistical Test	df	F	p	Sig
Face Inversion	OMNIBUS				
	Orientation	1, 56	17.1	.000	****
	Age Group	1, 56	14.6	.000	****
	Experimental Group	1, 56	12.3	.001	****
	Orientation × Age Group	1, 56	0.0	1.000	
	Orientation × Experimental Group	1, 56	0.2	.674	
	Age Group × Experimental Group	1, 56	1.1	.309	
	Orientation × Age group × Experimental Group	1, 56	0.0	.881	
	Children Only				
	Orientation	1, 28	6.0	.021	**
	Experimental Group	1, 28	10.9	.003	****
	Orientation × Experimental Group	1, 28	0.1	.737	
	Adults Only				
	Orientation	1, 28	14.9	.001	****
	Experimental Group	1, 28	2.9	.097	
	Orientation × Experimental Group	1, 28	0.6	.801	
	TD Only				
	Orientation	1, 28	20.5	.000	****
	Age Group	1, 28	5.8	.023	**
	Orientation × Age Group	1, 28	0.0	.882	
	HFA Only				
	Orientation	1, 28	4.6	.040	*
	Age Group	1, 28	8.9	.006	***
	Orientation × Age Group	1, 28	0.0	.931	
Face Classification Level	OMNIBUS				
	Condition	1, 56	7.2	.010	***
	Age Group	1, 56	10.2	.002	****
	Experimental Group	1, 56	9.7	.003	****
	Condition × Age Group	1, 56	0.2	.659	
	Condition × Experimental Group	1, 56	0.4	.554	
	Age Group × Experimental Group	1, 56	0.9	.348	
	Condition × Age Group × Experimental Group	1, 56	0.9	.340	
	Children Only				
	Condition	1, 28	1.7	.209	
	Experimental Group	1, 28	8.0	.009	***
	Condition × Experimental Group	1, 28	0.8	.376	
	Adults Only				

Task	Statistical Test	df	F	p	Sig
	Condition	1, 28	9.8	.004	****
	Experimental Group	1, 28	2.4	.131	
	Condition × Experimental Group	1, 28	0.1	.715	
	TD Only				
	Condition	1, 28	2.3	.143	
	Age Group	1, 28	4.3	.047	*
	Condition × Age Group	1, 28	1.0	.317	
	HFA Only				
	Condition	1, 28	5.1	.032	*
	Age Group	1, 28	6.1	.020	**
	Condition × Age Group	1, 28	0.1	.722	
Greeble Classification Level	OMNIBUS				
	Condition	1, 56	59.2	.000	****
	Age Group	1, 56	4.0	.051	
	Experimental Group	1, 56	4.6	.036	*
	Condition × Age Group	1, 56	4.7	.034	*
	Condition × Experimental Group	1, 56	6.1	.017	**
	Age Group × Experimental Group	1, 56	0.5	.477	
	Condition × Age Group × Experimental Group	1, 56	2.1	.154	
	Children Only				
	Condition	1, 28	53.4	.000	****
	Experimental Group	1, 28	1.1	.300	
	Condition × Experimental Group	1, 28	0.6	.456	
	Adults Only				
	Condition	1, 28	14.0	.001	****
	Experimental Group	1, 28	3.8	.061	
	Condition × Experimental Group	1, 28	7.0	.013	**
	TD Only				
	Condition	1, 28	26.1	.000	****
	Age Group	1, 28	4.0	.056	
	Condition × Age Group	1, 28	12.4	.001	****
	HFA Only				
	Condition	1, 28	35.0	.000	****
	Age Group	1, 28	0.7	.389	
	Condition × Age Group	1, 28	.02	.677	
Object Classification Level	OMNIBUS				
	Condition	1, 56	68.9	.000	****
	Age Group	1, 56	13.1	.001	****
	Experimental Group	1, 56	3.3	.076	

Task	Statistical Test	df	F	p	Sig
	Condition × Age Group	1, 56	11.0	.002	****
	Condition × Experimental Group	1, 56	.9	.360	
	Age Group × Experimental Group	1, 56	2.8	.100	
	Condition × Age Group × Experimental Group	1, 56	.000	1.000	
	Children Only				
	Condition	1, 28	58.0	.000	****
	Experimental Group	1, 28	5.9	.022	**
	Condition × Experimental Group	1, 28	0.4	.550	
	Adults Only				
	Condition	1, 28	14.8	.001	****
	Experimental Group	1, 28	0.0	.921	
	Condition × Experimental Group	1, 28	0.5	.482	
	TD Only				
	Condition	1, 28	26.7	.000	****
	Age Group	1, 28	2.1	.159	
	Condition × Age Group	1, 28	5.4	.027	*
	HFA Only				
	Condition	1, 28	43.3	.000	****
	Age Group	1, 28	12.8	.001	****
	Condition × Age Group	1, 28	5.6	.025	**
All Categories Classification Level	OMNIBUS				
	Category	2, 112	12.4	.000	****
	Condition	1, 56	84.9	.000	****
	Age Group	1, 56	13.8	.000	****
	Experimental Group	1, 56	10.1	.002	****
	Age Group × Experimental Group	1, 56	.602	.441	
	Category × Age Group	2, 112	2.6	.082	
	Category × Experimental Group	2, 112	3.6	.031	*
	Category × Age Group × Experimental Group	2, 112	1.8	.176	
	Condition × Age Group	1, 56	5.6	.022	**
	Condition × Experimental Group	1, 56	3.7	.061	
	Condition × Experimental Group × Age Group	1, 56	0.0	.963	
	Condition × Category	2, 112	7.0	.001	****
	Condition × Category × Age Group	2, 112	4.0	.021	**
	Condition × Category × Experimental Group	2, 112	0.6	.541	
	Condition × Category × Experimental Group X Age Group	2, 112	1.5	.221	
	Children Only				
	Category	2, 56	12.1	.000	****

Task	Statistical Test	df	F	p	Sig
	Condition	1, 28	56.0	.000	****
	Experimental Group	1, 28	8.0	.008	***
	Category × Experimental Group	2, 56	3.4	.039	*
	Condition × Experimental Group	1, 28	1.5	.238	
	Category × Condition	2, 56	8.3	.001	****
	Category × Condition × Experimental Group	2, 56	0.1	.880	
	Adults Only				
	Category	2, 56	2.6	.086	
	Condition	1, 28	29.2	.000	****
	Experimental Group	1, 28	2.8	.104	
	Category × Experimental Group	2, 56	1.9	.164	
	Condition × Experimental Group	1, 28	2.4	.133	
	Category × Condition	2, 56	0.3	.725	
	Category × Condition × Experimental Group	2, 56	2.8	.067	
	TD only				
	Category	2, 56	1.9	.163	
	Condition	1, 28	28.7	.000	****
	Age Group	1, 28	5.9	.022	**
	Category × Age Group	2, 56	0.8	.468	
	Condition × Age Group	1, 28	3.1	.088	
	Category × Condition	2, 56	3.8	.029	*
	Category × Condition × Age Group	2, 56	5.1	.009	***
	HFA Only				
	Category	2, 56	11.4	.000	****
	Condition	1, 28	57.7	.000	****
	Age Group	1, 28	8.0	.008	***
	Category × Age Group	2, 56	2.9	.062	
	Condition × Age Group	1, 28	2.5	.125	
	Category × Condition	2, 56	3.9	.027	*
	Category × Condition × Age Group	2, 56	1.1	.344	

Note: Age Group includes Children and Adults; Condition includes Gender/Subordinate and Individual/Exemplar conditions; Category includes faces, Greebles and Objects; Experimental Group includes Typically-Developing (TD) and High-Functioning Autism (HFA) groups.

p < .005.

p < .01,

**
p < .025,

*
p < .05

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 age in A) TD participants and B) HFA participants.

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 age in A) TD participants and B) HFA participants.

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 age in A) TD participants and B) HFA participants.

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 age in A) TD participants and B) HFA participants.

Demographic characteristics of Typically-Developing (TD) and High-Functioning Autism (HFA) Participants

Table 1

	Age	VIQ	PIQ	FSIQ	ADOS		
					Social	Communication	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),

** $p < .01$,

* $p < .05$.