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A fine-grained analysis of facial expression processing in high-functioning adults with autism

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Abstract

It is unclear whether individuals with autism are impaired at recognizing basic facial expressions, and whether, if any impairment exists, it applies to expression processing in general, or to certain expressions, in particular. To evaluate these alternatives, we adopted a fine-grained analysis of facial expression processing in autism. Specifically, we used the 'facial expression megamix' paradigm [Young, A. W., Rowland, D., Calder, A. J, Etcoff, N. L., Seth, A., & Perrett, D. I. (1997). Facial expression megamix: Tests of dimensional and category accounts of emotion recognition *Cognition and Emotion, 14*, 39–60] in which adults with autism and a typically developing comparison group performed a six alternative forced-choice response to morphs of all possible combinations of the six basic expressions identified by Ekman [Ekman, P. (1972). Universals and cultural differences in facial expressions of emotion. In J. K. Cole (Ed.), *Nebraska symposium on motivation: vol. 1971*, (pp. 207–283). Lincoln, Nebraska: University of Nebraska Press] (happiness, sadness, disgust, anger, fear and surprise). Clear differences were evident between the two groups, most obviously in the recognition of fear, but also in the recognition of disgust and happiness. A second experiment demonstrated that individuals with autism are able to discriminate between different emotional images and suggests that low-level perceptual difficulties do not underlie the difficulties with emotion recognition.

Keywords: Face processing; Emotion; Developmental disorders

1. Introduction

Autism is a neurodevelopmental condition characterized by impairments in communication and social cognition, and repetitive, stereotyped behaviors. Facial expression processing has been the focus of much attention in the condition (e.g. Adolphs, Sears, & Piven, 2001; Ashwin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, in press; Critchley et al., 2000; Davies, Bishop, Manstead, & Tantam, 1994; Teunisse & de Gelder, 1994, 2001). This is for multiple reasons, including the difficulties with face identity processing seen in autism (e.g. Behrmann, Thomas, & Humphreys, 2006) and possible links with theory of mind impairments (Baron-Cohen et al., 1994), with the obvious ramifications for social skills. Surprisingly, however, given the social implications of understanding facial expression, it is still unclear whether individuals with autism are impaired at recognizing basic facial expressions, although they do appear to have problems with more subtle or cognitive expressions such as arrogance or flirtatiousness (e.g. Baron-Cohen, Jolliffe, Martimore, & Robertson, 1997; Kleinman, Marciano, & Ault, 2001). While many studies have revealed difficulties with basic expressions (e.g. Celani, Battachi, & Arcidiacono, 1999; Davies et al., 1994; Hobson, 1986a,b; Hobson, Ouston, & Lee, 1988; Langdell, 1978), others have not (e.g. Adolphs et al., 2001; Baron-Cohen et al., 1997; Grossman, Klin, Carter, & Volkmar, 2000; Ogai et al., 2003; Ozonoff, Pennington, & Rogers, 1990; Prior, Dahlstrom, & Squires, 1990; Spezio, Adolphs, Hurley, & Piven, 2007; Teunisse and de Gelder, 1994; Volkmar, Sparrow, Rende, & Cohen, 1989).

Even if a deficit in facial expression processing exists in autism, it is not evident whether all expressions are implicated and if so, whether this is to an equal extent. Whereas one study reported relative impairments in the recognition of anger and disgust (Ellis & Leafhead, 1996), another found that a group of children with autism were impaired at recognizing surprise, but not happiness or sadness (disgust, fear and anger were not

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tested) (Baron-Cohen, Spitz, & Cross, 1993). Yet other studies report greater difficulties in the recognition of fear than the other five basic expressions although some difficulties with anger were also noted (Howard et al., 2000; Giola & Brosgole, 1988; Pelphrey et al., 2002). Teunisse and de Gelder (2001) found that performance on a morphed continuum between happiness and sadness was at the level of typically developing individuals but that recognition of the other two continua tested (anger–sadness and anger–fear) was impaired.

One reason for the lack of consensus amongst these findings may be that, in high-functioning individuals with autism, impairments in processing basic expressions may be relatively subtle, if present, and not all studies succeed in uncovering the subtle deficits. Additionally, some studies do not contain comparison groups (e.g. Adolphs et al., 2001), not all previous studies have matched appropriately the autism and comparison groups (e.g. Teunisse & de Gelder, 2001), and some of these studies have not measured verbal ability or IQ in their autism group. It is also the case that some studies test facial emotion processing in children (e.g. Davies et al., 1994), while other studies test it in adults (e.g. Adolphs et al., 2001), and it is possible that development might play a role in the discrepant findings. The aim of the present studies was to uncover possible subtle impairments, which may exist in facial expression processing in adults with autism using morphed expressions and a well-matched comparison group. Although a previous study has used morphed expressions to investigate facial expression processing in high-functioning adolescents with autism, only three different morphed continua – anger–sadness, anger–fear and happiness–sadness – were used in a two alternative forced-choice paradigm (Teunisse & de Gelder, 2001). To allow for a full exploration of expression processing and a much more complete test of the questions at issue, we compare the performance of individuals with autism and well-matched controls on a fifteen morphed expression continua and a six alternative, rather than a two alternative, forced choice. We also investigated whether there were relationships between the degree of any impairment and the severity of autism symptoms in the individual and, finally, we consider possible explanations for the pattern of impairment we uncover.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty high-functioning individuals with autism and 18 IQ-matched typically developing comparison individuals took part (see Table 1). The diagnosis of autism was established using the Autism Diagnostic Interview-Revised (ADI-R) (Lord, Rutter, & Le Couteur, 1994), the ADOS (social and communication domains; Lord et al., 2000) and expert clinical diagnosis. It was not possible to administer the ADI-R for three participants with autism, for whom no living relatives who could complete the inventory were available. One participant (A13) did not meet the criteria on the ADI-R, but in the expert clinical opinion of the second author (NM), he still merited a diagnosis of autism. Individuals were excluded if they had an associated condition such as fragile-X syndrome or tuberous sclerosis. All participants had normal or corrected-to-normal vision.

The comparison participants were community volunteers matched to the participants with autism approximately on age and IQ, as measured on the Wechsler abbreviated scale of intelligence (WASI^{TM} The Psychological Corporation, 1999) (see Table 1). The mean ages of the groups were: autism 24 years (S.D. 9 years), comparison group 28 years (S.D. 10 years), and the mean IQs were: autism VIQ 102 (S.D. 14) PIQ 105 (S.D. 15) FSIQ 103 (S.D. 15); comparison group VIQ 107 (S.D. 11) PIQ 108 (S.D. 7) FSIQ 109 (S.D. 9). *T*-tests confirmed that there were no significant differences between the two groups on age or any IQ measure (age, $t(36) = 1.15$, $p = 0.26$; VIQ, $t(36) = 1.30$, $p = 0.20$; PIQ, $t(36) = 0.91$, $p = 0.37$, FSIQ, $t(36) = 1.40$, $p = 0.17$).

The Benton facial recognition test (BFRT; Benton, Sivan, Hamsher, Varney, & Spreen, 1994), a standard neuropsychological test of face matching, that involves matching face identity across changes in lighting and viewpoint, was administered to 18/20 of the participants with autism.

Written informed consent was obtained from all participants or their guardians, using procedures approved by the University of Pittsburgh Medical Center Institutional Review Board and by the Carnegie Mellon University Institutional Review Board.

2.1.2. Stimuli and apparatus

Stimuli were taken from the Facial Expressions of Emotion: Stimuli and Test (FEEST) (Young, Perrett, Calder, Sprengelmeyer, & Ekman, 2002) set of morphed facial expressions (see Fig. 1 for an example).

Further details of the stimuli can be found in Young et al. (1997) but, briefly, black and white photographs of face JJ (Ekman & Friesen, 1976) showing happiness, surprise, fear, sadness, disgust and anger, were morphed in all possible pairwise combinations. The proportions of the blend in each continuum were 90:10, 70:30, 50:50, 30:70 and 10:90 (e.g. 90% fear 10% surprise etc for the fear–surprise continuum). Each continuum is labeled by the emotions at each end: fear–surprise is FS and then the proportion of the second emotion is included (FS10 indicates 10% surprise which implies 90% fear. The other expressions are abbreviated as follows: anger, A; disgust, D; happiness, H; sadness, M). The prototype (100%) expressions were not used. Thus, there were 15 different continua, each consisting of five images, i.e. 75 faces in total. Each morphed face measured 11.4 cm horizontally and 14 cm vertically and was viewed from a distance of approximately 0.6 m.

2.1.3. Procedure

The 75 morphed facial expressions were presented one at a time centrally using E-Prime (Psychology Software Tools Inc.) on a Dell laptop screen, in a random order, and stayed visible until response. The task was to decide which prototypical expression the image most resembled. Responses were made using six labeled keys on the keyboard. No feedback was given as to the accuracy of the response. There were seven practice trials, and following this, 11 blocks of 75 test trials. Due to fatigue or failure to cooperate for the duration of the experimental session, two participants with autism completed nine blocks, one completed six blocks and one completed four blocks. For all participants, responses were averaged across all presentations of a particular expression morph. In contrast to the original Young et al. (1997) study, there was no time limit for responding as we anticipated that people with autism would respond more slowly than controls (e.g. Behrmann, Avidan, et al., 2006), and we wished to maximize accuracy. The task took between 25 min and 1 h, depending on the speed of the individual's responses.

2.2. Results

We first discuss correct recognition of the unambiguous expressions (those which contained 90% of a particular expression) and present confusability matrices for these expressions. We then briefly present the correct recognition results for the 70% and 50% expressions and look at all responses for all 75 expression blends together.

2.2.1. Recognition of unambiguous (90%) expressions

For each expression, results were obtained by pooling over all five stimuli containing that 90% expression (e.g. the 'happiness' results are the average of 90% happiness mixed with each of 10% fear, sadness, disgust, surprise and anger). Mean accuracy and mean log reaction times for the group with autism and IQ-matched comparison group are shown in Fig. 2a and b.

Table 1
Background information for participants with autism (A) and gender-, age- and IQ-matched comparison individuals (C)

Participant	Exp1	Exp2	Sex	Age	VIQ	PIQ	FSIQ	Benton	ADOS COMM	ADOS SOC	ADOS TOTAL	ADI Soc	ADI Comm	ADI Rep
A1	x	x	M	20	97	119	107	n/a	4	8	12	22	10	3
A2	x		F	43	80	77	77	32	6	12	18	12	10	6
A3	x		M	32	104	116	110	48	5	7	12	21	16	8
A4	x	x	M	25	116	116	118	46	6	5	11	38	17	13
A5	x		M	19	95	95	95	32	5	11	16	20	16	7
A6	x	x	M	18	109	88	99	n/a	6	11	17	27	22	5
A7	x		M	21	96	75	84	37	6	10	16	25	13	4
A8	x		M	19	100	100	100	48	4	12	16	21	15	8
A9	x	x	M	21	83	110	96	43	6	9	15	31	21	13
A10		x	M	22	112	117	116	51	5	9	14	44	27	19
A11	x		M	50	76	100	86	45	10	7	17	10	13	6
A12	x	x	M	21	107	108	108	29	4	11	15	n/a	n/a	n/a
A13	x	x	M	22	88	101	78	41	6	11	17	4	4	3
A14	x		M	28	113	100	108	49	6	8	14	25	19	4
A15	x	x	M	19	112	109	112	49	2	9	11	19	13	6
A16	x	x	M	33	135	129	136	42	4	9	13	16	15	6
A17	x	x	M	18	111	121	118	48	5	13	18	n/a	n/a	n/a
A18	x	x	M	22	105	105	105	48	5	11	16	13	22	11
A19	x	x	M	20	119	129	127	40	5	13	18	n/a	n/a	n/a
A20	x	x	M	18	98	89	93	42	5	11	16	19	13	3
A21	x	x	M	16	99	115	107	46	5	8	13	23	17	4
C1	x	x	M	22	107	114	111	51	n/a	n/a	n/a	n/a	n/a	n/a
C2	x	x	M	27	112	119	117	49	n/a	n/a	n/a	n/a	n/a	n/a
C3	x		M	19	125	114	122	47	n/a	n/a	n/a	n/a	n/a	n/a
C4	x	x	M	23	89	109	99	40	n/a	n/a	n/a	n/a	n/a	n/a
C5	x	x	M	21	116	114	117	51	n/a	n/a	n/a	n/a	n/a	n/a
C6	x	x	M	21	98	98	99	48	n/a	n/a	n/a	n/a	n/a	n/a
C7	x	x	M	38	105	114	109	47	n/a	n/a	n/a	n/a	n/a	n/a
C8	x	x	M	22	108	106	108	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C9	x	x	M	22	113	115	116	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C10	x	x	M	20	94	99	96	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C11	x	x	M	40	107	118	113	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C12	x	x	M	39	102	115	109	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C13	x	x	M	22	106	96	100	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C14	x	x	M	55	115	104	111	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C15	x	x	M	22	105	109	108	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C16		x	M	45	87	83	83	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C17	x	x	M	33	99	100	100	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C18	x	x	M	29	138	114	129	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C19	x	x	M	24	98	99	99	n/a	n/a	n/a	n/a	n/a	n/a	n/a

A 2 (group) × 6 (expression) ANOVA on percentage correct revealed a significant interaction between group and expression, $F(3,117) = 4.24$, $p = 0.006$ and main effects of expression, $F(3,117) = 10.69$, $p < 0.001$ (with happiness recognized best and fear worst), and group, $F(1,36) = 10.08$, $p = 0.003$ (the former two Greenhouse–Geisser corrected). A Tukey HSD test ($q = 4.71$, $\alpha = 0.05$)) showed that the group with autism was significantly less accurate than the comparison group at recognizing fear, but not the other expressions. An ANOVA on the log-transformed reaction time data revealed significant main effects of expression, $F(3,105) = 16.25$, $p < 0.001$, and group, $F(1,35) = 11.84$, $p = 0.002$, with longer reaction times for the group with autism, but no interaction.

Given the known heterogeneity in autism, we further investigated how many individuals with autism fell more than two standard deviations below the mean accuracy score derived from the comparison individuals. This revealed a large degree of variability in the behavior of our sample with autism, with the results as follows: on accuracy (RT in parentheses), the following percentages of individuals were impaired: anger, 20% (30%); disgust, 20% (30%); fear, 50% (55%);

Fig. 1. Example of the fear–surprise continuum.

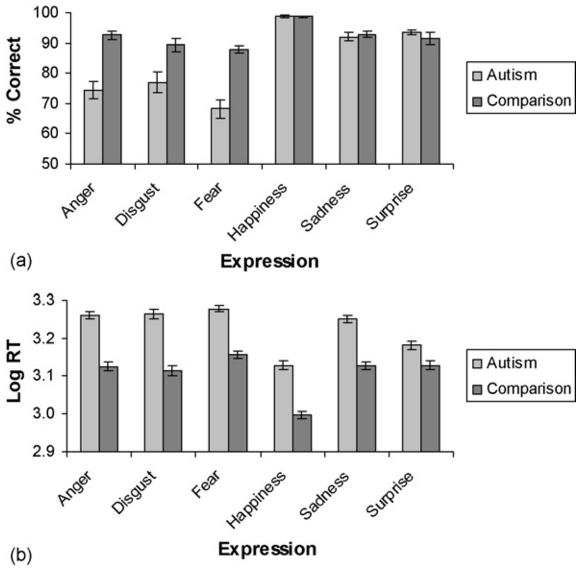

Fig. 2. Mean percentage correct identifications (a) and mean log reaction times (b) for the unambiguous (90%) expressions by the 20 participants with autism and IQ-matched comparison individuals (error bars S.E.M.).

Table 2
Confusability matrices for unambiguous expressions for (a) 20 participants with autism and (b) 18 group IQ-matched typically developing comparison individuals

Image	Response					
	Anger	Disgust	Fear	Happiness	Sadness	Surprise
(a) 20 participants with autism						
Anger	74.73	18.11	3.25	0.18	0.52	3.20
Disgust	20.94	74.37	0.93	0.09	3.05	0.61
Fear	6.76	2.10	63.51	2.10	4.44	21.09
Happiness	0.20	0.18	0.09	98.46	0.00	1.07
Sadness	1.88	4.14	1.59	0.09	91.25	1.05
Surprise	0.27	0.73	4.74	0.73	0.09	93.44
Total	104.79	99.63	74.11	101.65	99.35	120.47
(b) 18 group IQ-matched typically developing comparison individuals						
Anger	92.53	3.33	2.02	0.20	0.20	1.72
Disgust	8.38	89.39	0.10	0.40	1.41	0.30
Fear	4.55	0.10	87.88	0.51	1.01	5.96
Happiness	0.20	0.30	0.61	98.69	0.20	0.00
Sadness	1.11	3.43	0.30	2.12	92.83	0.20
Surprise	0.20	0.10	7.47	0.40	0.30	91.52
Total	106.97	96.67	98.38	102.32	95.96	99.70

For each of the six unambiguous (90%) expressions presented, these show the average percentage of each of the six possible responses (anger, disgust, fear, happiness, sadness, surprise) made by each group to that expression.

happiness, 5% (30%); sadness, 0% (45%) and surprise, 0% (15%). For the comparison individuals, the equivalent figures were 5.5% (0%); 5.5% (5.5%); 0% (5.5%); 0% (0%); 5.5% (0%); 5.5% (5.5%). Chi-square analyses (with Yates' correction) showed significant differences between these groups for accuracy, $\chi^2(1) = 10.00$, $p < 0.002$, and reaction time, $\chi^2(1) = 35.25$, $p < 0.001$.

Because of the variability in performance in the group with autism, we explored whether there was any relationship between the symptom severity, as measured by the ADOS social and communication algorithm scores and the ADI communication, repetitive behaviors and social interaction subscales, and the degree to which the individual expressions were recognized. Note that while these types of scores were not originally intended as a measure of the severity of autism, they are now used in this way (e.g. Joseph & Tager-Flusberg, 2004; Klin, Jones, Schultz, Volkmar, & Cohen, 2002). There were significant inverse correlations between the ADOS communication algorithm score, and the ADOS social and communication total algorithm score and accuracy at recognizing fear, (ADOS communication, $r = -0.593$, $p = 0.006$; ADOS total, $r = -0.460$, $p = 0.041$), and overall performance (ADOS communication, $r = -0.516$, $p = 0.020$; ADOS total, $r = -0.612$, $p = 0.004$), suggesting that the more severely affected individuals were worse at fear recognition specifically, and expression recognition more generally. The ADOS total algorithm score also correlated inversely with recognition of disgust ($r = 0.478$, $p = 0.033$) (more autistic individuals performed more poorly). No correlations with either of the ADI sub-scores reached significance.

We also investigated relationships between task performance and IQ and BFRT scores for the group with autism. Overall task performance correlated with IQ (VIQ = 0.520, $p = 0.019$; PIQ, $r = 0.488$, $p = 0.029$). Better performance on the BFRT by individuals with autism correlated with more accurate recognition of anger and surprise, as well as overall performance, and with faster recognition of anger and happiness (anger, $r = 0.838$, $p < 0.001$; surprise, $r = 0.554$, $p = 0.017$; overall, $r = 0.589$, $p = 0.01$; log RTs, anger, $r = -0.403$, $p = 0.046$; happiness, $r = -0.446$, $p = 0.025$).

Not surprisingly, the ADOS communication score (and as a result, the ADOS total score) correlated inversely with verbal IQ ($r = -0.540$, $p = 0.014$) and the Benton facial recognition scores correlated with performance IQ ($r = 0.568$, $p = 0.009$). In the light of the significant relationship between IQ and the BFRT, ADOS scores and overall performance, we reran all the correlations controlling for PIQ and VIQ. Controlling for these variables, there were significant correlations between the ADOS communication algorithm score, and speed and accuracy at recognizing fear (accuracy, $r = -0.683$, $p = 0.010$; RT, $r = 0.562$, $p = 0.046$). Better performance on the BFRT no longer correlated significantly with performance on any of the expressions, or overall.

Inspection of the ADOS communication scores revealed that participant A11 is apparently an outlier on this factor. We reran the correlations with the ADOS scores without him. The correlation between the ADOS communication algorithm score and impaired fear recognition was still significant without VIQ and PIQ partialled out, $r = -0.485$, $p = 0.035$, but not with VIQ and PIQ partialled out, $r = -0.401$, $p = 0.155$. Thus, we urge caution in interpreting this correlation.

Table 2a and b below show the confusability matrices for the two groups of participants for the unambiguous expressions, indicating which expressions were most often confused with one another. It can be seen that individuals with autism commonly misidentified disgust as anger and vice versa, and often mislabeled fear as 'surprise'. To a lesser extent, this was also true for the comparison participants, who also tended to mislabel surprise as 'fear'.

2.2.2. *Recognition of 70% expressions*

The results for the 70–30 blends are shown in Fig. 3. For brevity, we report only accuracy data.

An analysis of variance revealed both main effects of group, $F(1,36) = 19.57$, $p < 0.001$, and of expression, $F(3,115) = 17.75$, $p < 0.001$, with a significant inter-

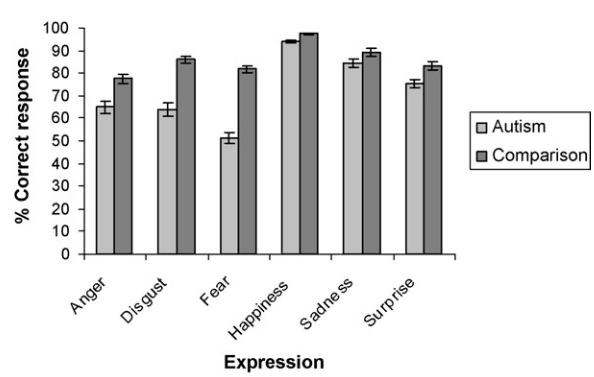

Fig. 3. Mean percentage correct identifications (a) and mean log reaction times (b) for the medium-strength (70%) expressions by the 20 participants with autism and IQ-matched comparison individuals (error bars S.E.M.).

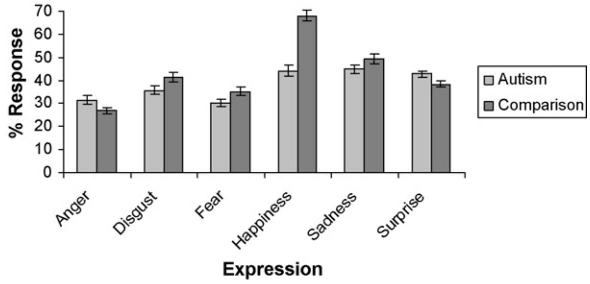

Fig. 4. Mean percentage anger, disgust, fear, happiness, sadness and surprise responses to 50% levels of these expressions for the 20 participants with autism and IQ-matched comparison individuals (error bars S.E.M.).

action between them, $F(3,115) = 4.46$, $p = 0.004$. Follow-up Tukey HSD tests ($q = 4.71$, $\alpha = 0.05$) revealed that the group with autism were significantly less accurate than the comparison group at identifying disgust and fear.

2.2.3. Recognition of 50% expressions

Unlike for the 90% or 70% expressions, there are no "correct answers" for these expression blends, so it was not possible to investigate percentage correct. For the purposes of analysis, we investigated the percentage of "anger" responses to all 5050 morphs containing "anger", the percentage of "disgust" responses to 5050 blends containing disgust, etc. (see Fig. 4).

An analysis of variance revealed both a main effect of group, $F(1,36) = 13.59$, $p = 0.001$, and a main effect of expression, $F(4,138) = 12.40$, $p < 0.001$, with a significant interaction between them, $F(4,138) = 3.46$, $p = 0.011$. Follow-up Tukey HSD tests ($q = 4.70$, $\alpha = 0.05$) revealed that the group with autism was significantly less likely than the comparison group to identify blends containing 50% happiness as happy; the comparison group did so on 68% of occasions (group with autism, 44%). This suggests that, unlike the individuals with autism, the comparison individuals were biased towards seeing happiness in ambiguous expressions.

2.2.4. Recognition of all expression morphs

In the above analyses, we investigated only the 'correct' (or the equivalent for the 50% blends) responses. However, it is also informative to look at the pattern of responses made overall, whether 'correct' or not, and we present these data here. Note that these analyses include the correct responses presented above but provide a comprehensive description of performance across all morphs and all expressions.

We do not consider reaction times for this set of data, because of the large number of empty cells (e.g. most people do not make "happiness" responses to sad pictures).

As can be seen (Fig. 5a–f), there are a number of similarities, but also a number of differences between the two groups. Both groups show similar peaks and troughs for each of the expression responses but there are a number of points where the two groups diverge. The most striking difference is for fear responses (Fig. 5c).

For each expression, we considered the response of the individual atypical if accuracy fell below 2 S.D. from the comparison group mean for more than 2 out of 75 expression blends presented. By this criterion, the percentage of individuals with autism showing impairment for each expression were anger, 30%; disgust, 35%; fear, 50%; happiness, 45%; sadness, 10%; surprise, 5%.

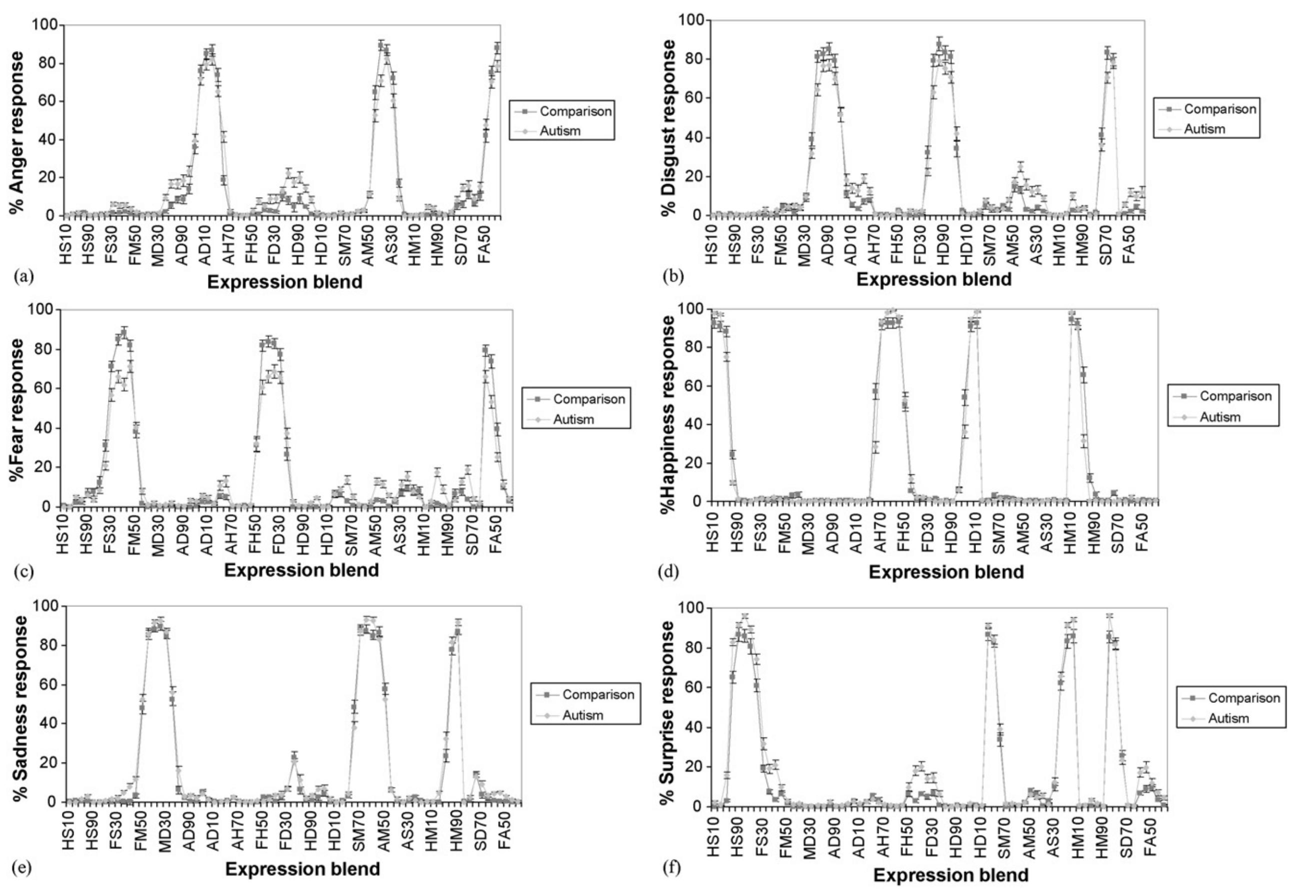

Fig. 5. Mean percentage responses by people with autism and the IQ-matched comparison group (a) anger (b) disgust (c) fear (d) happiness (e) sadness (f) surprise (error bars S.E.M.), Note that although these data are plotted as line graphs, we do not wish to imply that there is continuity in the perception of, for example, 10% happiness–90% surprise ('HS90') and 10% fear–90% surprise ('FS90'); a line graph, rather than a bar graph was chosen simply for ease of presentation, and has been utilized before in the literature (e.g. Dailey et al., 2002; Young et al., 1997).

(The equivalent figures for the comparison individuals were 5.5%, 5.5%, 0%, 5.5%, 16.7%, 5.5%.) Chi-square analyses (with Yates' correction) showed that the group difference was significant, $\chi^2(1) = 17.98$, $p < 0.001$.

An expression by group ANOVA on the number of responses of each type below 2S.D. from the IQ-matched comparison mean for the group with autism and IQ-matched comparison group showed a significant interaction between group and expression, $F(32,6) = 5.32$, $p = 0.001$, and significant main effects of expression, $F(4,133) = 4.32$, $p = 0.003$ and group, $F(1,36) = 14.25$, $p = 0.001$ (first two Greenhouse–Geisser corrected). Follow-up Tukey HSD tests ($q = 4.70$, $\alpha = 0.05$) revealed significantly more low responses for the autism group for fear.

There were significant correlations between the ADOS communication algorithm score and the number of responses below 2S.D. of the comparison group mean overall ($r = 0.485$, $p = 0.030$), and specifically for fear ($r = 0.564$, $p = 0.01$) and disgust ($r = 0.492$, $p = 0.027$). There was also a significant correlation between the ADOS social algorithm score and the number of sub-2S.D. responses for happiness ($r = 0.464$, $p = 0.039$). No correlations with the ADI sub-scores reached significance. We also investigated relationships between performance and verbal and performance IQ, and Benton face recognition task scores. These showed an inverse relationship between the Benton facial recognition score and the number of sub-2S.D. responses overall ($r = -0.536$, $p = 0.022$). The total number of sub-2S.D. responses also correlated significantly inversely with VIQ and PIQ, VIQ $= -0.457$, $p = 0.043$; PIQ, $r = -0.454$, $p = 0.044$. In the light of significant correlations between the ADOS communication score and BFRT score and IQ (described above), correlation analyses were run partialling out verbal and performance IQ. The correlation between the ADOS communication score and number of atypically low fear responses remained significant ($r = 0.566$, $p = 0.044$), and there was a significant inverse correlation between the BFRT score and low anger responses ($r = -0.662$, $p = 0.014$). We also reran the correlations with the ADOS communication score. There were significant correlations between the ADOS communication score and overall performance ($r = 0.524$, $p = 0.024$) and fear ($r = 0.508$, $p = 0.027$), but these failed to reach significance with IQ partialled out (overall, $r = 0.487$, $p = 0.108$; fear, $r = 0.501$, $p = 0.097$). Thus, we urge caution in the interpretation of these correlations.

2.3. Discussion

Experiment 1 revealed a number of similarities and also a number of differences in the way individuals with autism and a typically developing comparison group recognize facial expressions. Both groups showed some similarities in the pattern of their responses, as witnessed by the shapes of the response graphs. However, the groups also differed in several respects. In particular, marked differences were found for the recognition of 90% and 70% fear, and 70% disgust. Individuals with autism also showed less bias to categorize ambiguous expressions containing happiness as 'happy'. Of note, the degree to which a person with autism under-identified fear, relative to the comparison group, correlated significantly with the degree to which the individual was rated as having autistic traits according to the ADOS communication algorithm score (but note that this may be due to the presence of an outlier on this score, so should be interpreted with caution).

3. Experiment 2

Experiment 1 established that individuals with autism differ from typically developing comparison individuals in facial expression classification. One possibility is that these differences arise from a perceptual impairment in processing the stimuli in the group with autism rather than from a difficulty in the classification or identification of the emotion per se. Here, we test the ability to discriminate between the different facial expressions in a same/different perceptual task.

3.1. Method

3.1.1. Participants

Fourteen participants with autism and 18 comparison individuals took part in this experiment (see Table 1 for demographic details). All but one of each group also took part in Experiment 1. The mean ages of the groups were: autism 21 years (S.D. 4 years), comparison group 29 years (S.D. 10 years), and the mean IQs were: autism VIQ 106 (S.D. 13) PIQ 111 (S.D. 13) FSIQ 109 (S.D. 15); comparison group VIQ 106 (S.D. 12) PIQ 107 (S.D.10) FSIQ 107 (S.D. 10). *T*-tests confirmed that the two groups did not differ significantly in verbal, performance or full-scale IQ (VIQ, $t(30) = 0.23$, $p = 0.82$; PIQ, $t(30) = 1.06$, $p = 0.30$, FSIQ, $t(30) = 0.38$, $p = 0.71$). The comparison group were, however, significantly ($t(24) = 3.06$, $p = 0.005$) older than the group with autism. Note that Experiment 2 was always conducted first[1] except in a few cases and in those cases, several months separated the testing sessions[2].

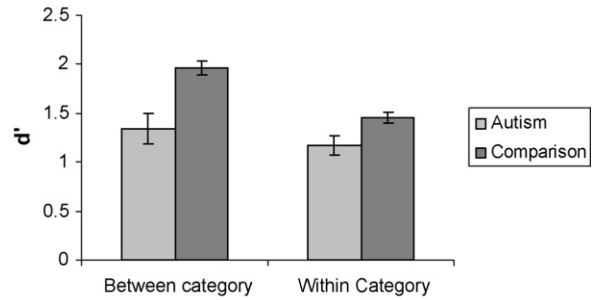

Fig. 6. Within and between categories mean d' scores for participants with autism and the IQ-matched comparison group (error bars S.E.M.).

3.1.2. Stimuli

The stimuli were six of the continua employed in Experiment 1: happiness–surprise; surprise–fear; fear–sadness; disgust–anger; anger; sadness–disgust. Only a subset of the full set of 15 continua was selected so that the experiment could be completed in a reasonable amount of time. The first four continua were chosen as they were the pairs of expressions most confused by our participants with autism in Experiment 1 (see Table 2a), and the anger–happiness and sadness–disgust were added so that each expression was represented an equal number of times in the stimulus set. The 30 expression stimuli (six expressions, five morph levels) were presented in pairs, horizontally across from one another. Half the pairs consisted of the same images, and half of two morphs which differed from one another by 20% (e.g. AD10 with AD30). Each individual face measured 6 cm (horizontal) by 7 cm (vertical) and the pair were separated by a horizontal distance of 2 cm.

3.1.3. Procedure

A central fixation cross was presented for 250 ms, followed by two simultaneous face images, viewed from a distance of approximately 0.6 m, which remained visible until the participants responded. Each pair of images was presented a total of six times in a randomized order for a total of 360 trials. Participants responded 'same' or 'different' using the keys marked 's' and 'd' on the keyboard. There were 20 practice trials during which feedback was given, but thereafter, no feedback was provided. The task took between 25 min and 1.5 h.

3.2. Results

We first present the mean discriminability (d')[3] scores for the groups (Fig. 6), followed by an analysis of the reaction times for correct responses. A mixed 2 (group) × 6 (continuum) × 5 (blend) ANOVA conducted on the d' data

[1] We conducted the experiments in this order since we intuited that categorizing and assigning verbal labels to stimuli (Experiment 1) might have more effect on their subsequent discrimination (Experiment 2), than vice versa (by, for example, reducing the discriminability of pairs to which participants had assigned the same verbal label). We describe the experiments here in the reverse order for ease of presentation.

[2] It is not possible to compare the performance of these two groups statistically (those who performed Experiment 1 or 2 first), as only a small number ($N = 3$) performed Experiment 1 first.

[3] For the purposes of calculating d′, 'same' and 'different' trials were paired together (e.g. 'same' AD30 trials were paired with 'different' AD30–AD10 trials).

revealed significant main effects of continuum, $F(5,150) = 35.13$, $p < 0.001$, and blend, $F(4,120) = 74.36$, $p < 0.001$, and a significant interaction between them, $F(20,600) = 4.94$, $p < 0.001$. There was no main effect of group, $F(1,30) = 0.922$, $p = 0.345$, nor any interaction involving group as a factor (all $p > 0.2$), indicating that the adults with autism were just as accurate at discriminating faces as the comparison group although they possibly used a different strategy.[4] A mixed two (group) by six (continuum) by 10 (image pair) ANOVA conducted on the log RTs for the correct trials ('hits') showed a significant main effect of continuum, $F(5,150) = 4.64$, $p = 0.001$, and a significant interaction between continuum and image pair, $F(45,1350) = 1.93$, $p < 0.001$. No other main effects or interactions were significant. These findings indicate that people with autism showed normal levels of performance on this discrimination task.

4. Discussion

The results of Experiment 2, which addressed the ability of individuals with autism to discriminate between different emotional expressions, independent of the ability to identify the actual expression, found no significant differences between the two groups in terms of discriminability or reaction times. This lack of an accuracy difference is unlikely to be due to a ceiling effect, since, if this were the case, differences would have shown up in the reaction times. While null results must be interpreted with caution, this result suggests that the difficulty in expression recognition in autism observed in Experiment 1 is not attributable to an inability to detect fine-grained components of the images, and that other explanations are necessary.

4.1. Relating the results from Experiments 1 and 2: is there evidence of categorical perception of facial expressions in autism?

Teunisse and de Gelder (2001) have previously reported that their sample of adolescents with autism failed to show normal categorical perception of blends of expressions. The generally accepted test of categorical perception is that individuals should show better discriminability of stimulus pairs that fall on either side of their own recognition boundaries for each continuum, than for stimulus pairs that fall on one side of the boundary. Since we have recognition data from Experiment 1 and discrimination data from Experiment 2, we can link the two and investigate whether this was the case in these studies. Inspection of the results so far suggests that the expression blends were perceived categorically by both groups. The response curves in Experiment 1 (Fig. 5a–f) show clear peaks corresponding to the different perceived expressions for both the autism and comparison groups. Similarly, in Experiment 2, there was lower discriminability for pairs around the prototypical, 90% expressions, than further away, again for both groups of individuals (both $p < 0.001$).

For each of the participants who took part in both Experiments 1 and 2, we used their recognition data from Experiment 1 to calculate their individual category boundaries for each of the six continua presented in Experiment 2 (e.g. for fear–surprise, the point along the continuum at which the proportions of fear and surprise responses were equal). It was not possible to identify a category boundary for the fear–sadness or fear–surprise continua for one participant with autism, or the sadness–disgust continuum for a second participant with autism; these two participants were excluded from the statistical analysis. We analyzed whether d' scores were higher for those expression pairs that straddled these boundaries than those that did not (note that the distance between the two faces in each pair was always the same). A 2 (group) × 6 (continuum) × 2 (within category versus between category) ANOVA showed that, as predicted, there was a main effect of within category versus between category, with d' scores significantly higher across category boundaries, $F(1,26) = 6.554$, $p = 0.017$. There was also a main effect of continuum, $F(5,130) = 23.545$, $p < 0.001$. There was no significant continuum by within–between categories interaction, $F(5,130) = 1.141$, $p = 0.342$. There was also no main effect of group, $F(1,26) = 3.176$, $p = 0.086$ (although this could be considered a slight trend), nor did it interact significantly with any other variable (all $p > 0.1$).

Despite the non-significant group × within–between categories interaction, we also conducted post hoc Tukey HSD tests ($q = 3.88$, $\alpha = 0.05$) comparing the within and between categories discrimination for each group, collapsed across continua (see Fig. 4). These revealed that, although there was a significant difference for the comparison group, the difference was not significant for the individuals with autism. Thus, our results suggest that facial expressions may be perceived less categorically by individuals with autism than comparison individuals, although this finding is rather subtle.

4.2. General discussion

The main aim of this research was to provide a detailed analysis of facial expression processing in adults with high-functioning autism using methods and measures sensitive enough to discern even subtle deficits. The major finding was that the adults with autism were impaired at recognizing fear. The degree of the impairments correlated with the individual's symptom severity, reflected by their communication score on the ADOS (although, note that this correlation should be interpreted with caution, given that it may be due to the presence of an outlier score on the ADOS). There were also group differences in the recognition of disgust. In addition, individuals with autism did not share the comparison group's bias towards classifying blends of 50% happiness as happy. Overall impairments correlated inversely with IQ. Despite the expression recognition difficulties, individuals with autism appeared to be able to *discriminate* different facial expressions, including fear, as accurately as a comparison group. They also showed some evidence of perceiving expressions categorically, although to a lesser extent than the comparison individuals.

[4] While we have no experimental evidence to support this assertion, anecdotally, many of the participants with autism, unlike the comparison group, spontaneously commented that they had chosen a particular pixel, or small group of pixels, to monitor, and performed the task on the basis of changes in these pixels, rather than the face as a whole. Interestingly, though, there is no evidence that this strategy was less efficient than that of the comparison individuals, as there was no group difference in reaction times.

4.3. Relationship to previous results

4.3.1. Expression recognition

The most striking recognition deficit we found for individuals with autism was in the recognition of fear. Ten out of twenty participants with autism fell more than 2S.D. below the comparison group mean in their recognition of unambiguous (90%) fear and only 4 of the 20 showed good (90%+) recognition of unambiguous fear. This specific deficit has been reported previously (Ashwin et al., in press; Howard et al., 2000; Pelphrey et al., 2002), and the present results confirm these existing findings. Impaired recognition of disgust has also been reported previously in participants with autism (Ashwin et al., in press; Ellis & Leafhead, 1996). The lack of bias to categorize 50% happiness as happy, shown by our sample of individuals with autism, has not previously been revealed, to our knowledge.

4.3.2. Expression discrimination

We found that adults with autism appear unimpaired at discriminating between subtle facial expressions, in terms of both accuracy and reaction times. That people with autism were impaired at expression recognition but not discrimination might lead one to deduce that the deficit is simply linguistic, one of labeling the expressions. We note that there was a significant correlation between overall performance and verbal IQ (Table 3), which might support this conclusion, although we suggest that a likely alternative to a linguistic deficit is that people with autism have difficulty identifying and categorizing the expressions perceptually.

Two recent studies have reported deficits in matching expressions across different facial identities in autism (Piggot et al., 2004; Wang, Dapretto, Hariri, Sigman, & Bookheimer, 2004). However, this task is somewhat more complex than our own, in which participants simply judged whether two *images* were identical. It was not our purpose, in the current experiments, to judge whether individuals with autism are able to match expressions, but rather, simply to demonstrate that any difficulties in recognizing the expressions in Experiment 1 were not due to any low-level perceptual impairments resulting in an inability to detect the images as different. It should in no way be concluded from our result that individuals with autism perform at normal levels at matching expressions when the images are not identical.

4.3.3. Variability within the group with autism

As in many studies of autism (e.g. Muller, Kleinhans, Kemmotsu, Pierce, & Courchesne, 2003), the variability among our participants with autism was striking. The number of image-response combinations for which individuals fell more than 2S.D. from the control mean ranged from 9 to 139. There were also qualitative differences between the individuals, with eight performing worst with anger, seven with fear, four with disgust and one with surprise. While we found significant group differences in processing fear, when we looked at individual patterns of performance, it was evident that only around half of the autism sample performed more than 2S.D. below the comparison group although many others showed similar trends. Therefore, not all of the adults with autism actually have frank deficits with recognition of fear. Rather, the extent to which this is the case correlated significantly with the ADOS communication algorithm score, suggesting that the more affected the individual, the worse their fear recognition. To our knowledge, this is the first study to report a relationship between ADOS scores and performance at facial expression recognition, but further replications are needed, particularly in the light of the fact that this relationship might be driven by an outlier on the ADOS communication score in this sample (A11).

4.4. Is the deficit visual?

One possibility is that the deficits seen in these studies are purely visual in nature, mediated either by a specific deficit affecting the perception of facial expressions (or deficits for fear and disgust individually), or arising as part of some more general visual alteration (Caron, Mottron, Berthiaume, & Dawson, 2006), impacting face perception, perception of configural information or even visual perception more generally. While people with autism performed at normal levels on the expression discrimination task in Experiment 2, it remains possible that atypical perceptual processing underpins their good performance. Many of the participants with autism commented that they performed the task by selecting a particular pixel or small region of the face and monitoring darkness or shape changes in this region, rather than processing the facial expression as a Gestalt, and this is consistent with the many reports of a local processing bias in autism (see Behrmann et al., 2006; Caron et al., 2006; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). We (Behrmann, Avidan, et al., 2006; Behrmann, Thomas, et al. 2006; Scherf, Behrmann, Minshew, & Luna, submitted for publication) have already established that individuals with autism have difficulties with holistic or configural processing, and that this is significantly related to their ability to discriminate faces at an individual level. It is not clear, however, whether the expressions with which our participants with autism had the most difficulty are those which rely most on 'configural', and least on part-based, processing, in typical individuals. One study (McKelvie, 1995) found that the recognition of anger, disgust, fear and sadness, but not happiness, rely on configural processing, but other studies have reported no such differences between the expressions (Calder, Young, Keane, & Dean, 2000; White, 2000).

Other alternative, although not necessarily mutually exclusive, explanations also exist. One possible mechanism (for which we have no direct evidence and is thus speculative) for the currently observed functional impairment with fear recognition might be the well-documented tendency for individuals with autism to avoid looking at the eyes of the face, and, instead, to concentrate on the lower half, particularly the mouth (e.g. Klin et al., 2002; Pelphrey et al., 2002; Spezio et al., 2007). Previous studies have found that occlusion or omission of the lower part of the face, or presentation of the eyes alone, leads to greater impaired performance on facial expression or identity processing tasks for people with autism than comparison groups (Baron-Cohen et al., 1997; Gross, 2004; Hobson et al., 1988).

Smith, Cottrell, Gosselin, and Schyns (2005), using the 'Bubbles' method (Gosselin & Schyns, 2001) to determine which regions of the face were used by typically developing adults, found that fear, in particular, was identified most effectively by the eye regions and anger by the eyes and eye-brows, whereas happy and surprised expressions were identified solely by the mouth, disgust by the nose and mouth, and sadness by the corners of the mouth and the forehead, with some low frequency information from the eye region. If individuals with autism are indeed fixating the mouth, rather than the eye regions of faces, this might explain why their most pronounced expression recognition deficits are with fear (we note that, in addition, there were also non-significant trends for our participants to show difficulties with anger, another 'eye region' expression) although it does not fully explain the difficulty with disgust, and the bias against calling an ambiguous blend 'happiness'. This failure to attend to the eye region (with the resulting difficulties with fear recognition) may stem from a failure of the amygdala to direct the visual system to attend to the eyes (Adolphs et al., 2005; Baron-Cohen et al., 2000; see also Adolphs et al., 2001; Bachevalier, 1994; Hetzler, & Griffin, 1981; Howard et al., 2000; Schultz, 2005). Multiple studies have demonstrated atypical amygdala activation in individuals with autism when viewing faces and facial expressions (e.g. Baron-Cohen et al., 1999; Critchley et al., 2000; Dalton et al., 2005; Pierce, Muller, Ambrose, Allen, & Courchesne, 2001). We speculate that the amygdala function may be more atypical in individuals with more pronounced symptomatology, as reflected in higher ADOS scores, and that this may result in more pronounced difficulties with fear, but this awaits further investigation.

It has also been suggested that a difference in valence of the expressions might account for the pattern of results we obtained, with 'positive' expressions generally well recognized, and more difficulties with negative expressions. However, this dichotomy does not map onto the results well, since 'surprise' (well recognized) is not necessarily a positive expression, and sadness (well recognized) is a negative expression. A further possibility is that simple exposure rates might account for the results, with expressions to which people with autism have had the most exposure better recognized than those with which they have had least experience. This might conceivably account, at least in part, for the lack of a 'happiness bias' in the individuals with autism, if we assume that they are less exposed to social smiling than most people but it is hard to envisage how it would give rise to the other results.

4.5. Limitations and future directions

The current set of studies has explored the facial expression deficits in autism in a fine-grained fashion. We have shown that there are indeed deficits affecting recognition of many facial expressions, but some (particularly fear and disgust) to a greater extent than others. We have already suggested some avenues for future research. However, there are a number of other outstanding issues which future studies could address. We used static stimuli, but there is a large body of evidence demonstrating the importance of dynamic information for facial expression recognition (see O'Toole, Roark, & Abdi, 2002 for a review) and further studies would be well advised to make use of such images. Performance by individuals with autism with these more naturalistic stimuli, which require rapid processing and more complex information processing, might be even poorer relative to performance seen with our stimuli. However, it should also be noted that although dynamic stimuli may be more ecologically valid, there is recent evidence of impairments in the ability to perceive coherent (Bertone, Mottron, Jelenic, & Faubert, 2003, 2005; Milne et al., 2002; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005) and biological (Blake, Turner, Smoski, Pozdol, & Stone, 2003) motion in autism. Therefore, the use of dynamic stimuli could potentially confound the results of any such study.

The stimuli we used were of only one face identity (Ekman and Friesen's 'JJ'), and, furthermore, this identity was unfamiliar to individuals with autism. Different results might be obtained with a wider range of face identities and the use of individuals familiar to the participants (see Pierce, Haist, Sedaghat, & Courchesne, 2004, for evidence that processing of personally familiar faces in individuals with autism is more convergent with that of controls than that of unfamiliar faces). While expression and identity processing have traditionally been thought of as separate processes, there is growing evidence that the two are not completely independent (Ganel & Goshen-Gottstein, 2004; see Robel et al., 2004 for a relevant recent study with children with autism) and an analysis of these dimensions in autism is clearly needed. However, here we found no correlation between scores on the BFRT and accuracy scores on the various expressions, once IQ was partialled out (p. 8), suggesting that these processes might be independent in this sample of individuals with autism.

Finally, as ever with studies involving participants with autism, there is the challenge of the heterogeneity of the population, and the degree to which results from any one study generalize to all individuals with autism. Only high-functioning adults were involved in the present set of experiments and we cannot claim that results would generalize to lower functioning autistics. However, it seems unlikely that if high-functioning individuals display a deficit that lower functioning individuals would show no deficits in this area. Further studies are needed to test this empirically.

Despite decades of work investigating facial expression recognition deficits in autism there has been little consensus as to whether a deficit exists, and if so, whether it affects recognition of all expressions or just a subset. The results of the present study show that facial expression recognition deficits exist even in high-functioning adult individuals with autism, but that subtle, fine-grained methods may be necessary to detect some of them. There also appears to be a high degree of variability among the individuals, which seems to correlate with the severity of symptoms. However, at a group level, using a large number of graded stimuli, we were able to demonstrate clear deficits in the recognition of basic expressions, particularly affecting fear, anger and disgust. We suggest that a failure to attend to the eye regions of the face in autism may contribute to these difficulties, a hypothesis that awaits direct testing and confirmation.

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