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REVIEW

Facial Emotion Recognition in Autism Spectrum Disorders: A Review of Behavioral and Neuroimaging Studies

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Abstract Behavioral studies of facial emotion recognition (FER) in autism spectrum disorders (ASD) have yielded mixed results. Here we address demographic and experiment-related factors that may account for these inconsistent findings. We also discuss the possibility that compensatory mechanisms might enable some individuals with ASD to perform well on certain types of FER tasks in spite of atypical processing of the stimuli, and difficulties with real-life emotion recognition. Evidence for such mechanisms comes in part from eye-tracking, electrophysiological, and brain imaging studies, which often show abnormal eye gaze patterns, delayed event-related-potential components in response to face stimuli, and anomalous activity in emotion-processing circuitry in ASD, in spite of intact behavioral performance during FER tasks. We suggest that future studies of FER in ASD: 1) incorporate longitudinal (or cross-sectional) designs to examine the developmental trajectory of (or age-related changes in) FER in ASD and 2) employ behavioral and brain imaging paradigms that can identify and characterize compensatory mechanisms or atypical processing styles in these individuals.

Keywords Autism · Face perception · Emotion · Neuroimaging · Eye-tracking · Electrophysiology

The ability to discern emotion from facial expressions is essential for successful social interaction, and the reverse may be true as well: social interaction, by increasing one's experience with expressive faces, may be necessary for the typical development of facial emotion recognition (FER) (Leppanen and Nelson 2006). It is therefore unsurprising that many individuals with an autism spectrum disorder (ASD), a grouping of disorders characterized by profound difficulties with social interaction, have demonstrated impairments in FER. Indeed, Kanner (1943) originally described autism as a 'disorder of *affective* contact,' and the current DSM-IV-TR diagnostic criteria for ASD include items related to deficits in identifying and processing emotion: "marked impairments in the use of multiple nonverbal behaviors, such as…facial expression…" and "lack of social or emotional reciprocity" (APA 2000). However, findings on FER in ASD are inconsistent: some studies have found intact FER in ASD, while others find profound deficits. In this review, we attempt to account for contradictory findings in previous research and offer suggestions for how future research might address these discrepancies.

We searched for studies published through April 2010 that focused primarily on FER in ASD. To do so, we input the search terms "Autism," "Autism Spectrum Disorder," or "ASD," "face" or "facial," and "emotion" using the databases PubMed and Web of Science. Furthermore, we examined the references lists of the articles found through the above literature search in order to identify additional relevant studies. We did not include studies that examined only facial identity recognition or other non-affective facial processing.

Based on a synthesis of these studies, we propose that three factors account for a great deal of the discrepant findings regarding FER in ASD: demographic characteristics of the participant group, task demands, and which dependent variables were measured. We also address the possibility that individuals with ASD identify facial

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expressions through different mechanisms than typically developing (TD) controls, even when their behavioral performance is intact. Ultimately, we suggest that future experimental studies utilize tasks, stimuli, and dependent variable measurements that are sensitive to these compensatory mechanisms. At the same time, additional cross-sectional studies of varying age groups and longitudinal investigations are needed in order to document whether the development of FER in ASD follows a normal, delayed, or deviant trajectory.

Demographic Factors

ASD, as a clustering of clinical diagnoses, is heterogeneous. Even the more specific classifications of autism, Asperger's syndrome, and pervasive developmental disorder-not otherwise specified (PDD-NOS) do not fully capture this heterogeneity at a neurobiological level (e.g., Amaral et al. 2008). This issue is made evident by DSM-V's proposal to collapse these three diagnoses under the rubric 'Autism Spectrum Disorder' (Proposed Revision: APA DSM-5, 2010). Accordingly, FER in ASD may vary considerably, though not corresponding to the current DSM-IV diagnostic distinctions when IQ differences are taken into account (Mazefsky & Oswald, 2007). It is possible that some individuals, especially on the mild end of the autism spectrum, have no difficulty recognizing facial expressions, even outside of an experimental setting. However, since each of the three DSM-IV diagnoses shares the core social deficit that defines ASD, we consider it unlikely that differences in the diagnostic composition of ASD samples in the reviewed studies plays a large role in the variable findings.

One demographic factor that is likely to influence behavioral findings on FER in ASD is age of the sample. In TD children, emotion decoding improves throughout much of childhood (Vicari et al. 2000) and into adolescence (Thomas et al. 2007). The typical developmental trajectory of FER is emotion-dependent: among the six basic emotions (i.e., happiness, sadness, anger, fear, surprise, and disgust), happiness tends to be recognized earliest, and surprise and fear tend to be recognized last (Herba and Phillips 2004). Although, to our knowledge, no longitudinal studies of FER in ASD have been conducted, several cross-sectional studies provide some evidence that FER improves less over time in children with ASD than in TD children. In one study of young children, FER performance was correlated with age in the TD, but not the ASD group (Gepner et al. 2001). Another study found no differences in performance between high-functioning school age children with ASD and high-functioning adults with ASD, with only adults showing diminished performance compared to controls (O'Connor et al. 2005). A third study found FER deficits in young children and adults with high-functioning autism, but no deficits in older children and adolescents with the disorder, and no improvement with age in the autism group (Rump et al. 2009). Although one study (Kuusikko et al. 2009) did find superior FER in adolescents and young adults with ASD as compared to children with ASD, the pattern of age-related FER improvement in ASD may be altered.

The ages of participants could affect findings regarding group differences in FER for three reasons. First, one might expect studies involving adults to be more likely to find deficits in ASD, especially if tasks are more complex than those used in studies with children. Second, difficulty with FER in the control group due to a very young age, but not to social deficits, might mute FER deficits in a young and/or low-functioning ASD group because of floor effects. Third, age and level of functioning are conflated in the literature: studies with children are more likely to include low-functioning ASD populations (IQ<70), while studies with adolescents and adults more often include high-functioning (IQ≥70) individuals with ASD—in fact, studies with low-functioning adults are virtually non-existent (although diagnostic bias may contribute to this situation as high-functioning individuals are often identified later). Yet efforts should be made to disentangle the roles of these two factors, as higher cognitive ability, apart from age, might contribute to FER (Loveland et al. 1997; Buitelaar et al. 1999).

Studies of Children

The results of studies examining FER in children and younger adolescents with ASD have been mixed (see Tables 1 or 2 for a list of studies and their findings). Many reveal broad FER deficits in both low-functioning (Celani et al. 1999; Hobson 1986) and high-functioning ASD (Hobson 1986; Lindner and Rosen 2006; Tantam et al. 1989), while others report intact FER (Capps et al. 1992; Prior et al. 1990; Robel et al. 2004). Some of the studies that found no group differences in children might be biased by the procedure used to match ASD and control groups on intellectual ability (Burack et al. 2004). Some data suggest that FER is more dependent on intellectual ability in children with ASD than in typical development (Dyck et al. 2006; Hobson 1986), so carefully matching groups for intellectual ability is especially important in studies on this topic. Furthermore, due to a common profile in classical autism in which verbal IQ is substantially lower than nonverbal IQ, an individual with autism may have a higher nonverbal IQ than a control participant with the same verbal IQ. Thus, matching groups on verbal ability, while disregarding nonverbal ability, or vice versa, may be problematic. In addition to social-emotional competence, a minimum level of both nonverbal and verbal mental age may be required to pass FER tasks, and if one group falls below this threshold on either index (i.e., if the ASD group does not meet a verbal ability threshold, or the TD group does not meet a nonverbal ability threshold), group differences in the FER task may be artificially inflated or decreased.

In support of this proposal, three studies involving young children have found differences in matching facial expressions in children with ASD compared to nonverbal ability-matched TD controls but no differences compared to verbal ability-matched controls (Braverman et al. 1989; Fein et al. 1992; Ozonoff et al. 1990). However, in Ozonoff et al.'s study, the ASD group also performed worse than nonverbal IQ-matched controls on a non-emotional control task. This may have been related to floor effects due to the very young mean ages of the subjects (6.4 years in the ASD group, and 4.1 years in the TD group). Four other studies that matched low-functioning children with autism to TD and intellectually disabled (ID) children based on verbal, but not nonverbal ability, found no FER differences between groups (Castelli 2005; Davies et al. 1994; Loveland et al. 1997; Prior et al. 1990), although one such study did show group FER differences in delayed matching and valence sorting tasks (Celani et al. 1999). The behavioral studies that matched children on nonverbal, but not verbal IQ (Bormann-Kischkel et al. 1995; Macdonald et al. 1989; Tantam et al. 1989) did find FER deficits in ASD, although Tantam and colleagues controlled for verbal IQ in their analysis. That the matching criteria used seems to influence findings so consistently is a serious issue that future studies must address.

Of course, the issue of matching is confounded with that of uneven IQ profiles in studies involving those with more classical autism—due to the disparate IQ profile in these individuals, it is often impossible to match on both verbal and nonverbal ability. A separate IQ-related issue concerns the often greater variability in IQ scores among an ASD group than a TD group, even when means are matched. The only way to circumvent this problem would be to match participants individually. Some studies (e.g., Tantam et al. 1989) have statistically controlled for IQ to address the issue of uneven IQ profiles, which in addition to limiting statistical power might not be appropriate when studying pre-existing (instead of randomly assigned) groups (Miller and Chapman 2001). In this case, IQ (or at least, an uneven IQ profile) is phenotypically linked with ASD, so removing the effect of IQ would essentially remove some of the effects of group differences attributable to having an ASD diagnosis. The best solution may be to use two control groups, one matched for verbal ability, and the other for non-verbal ability, as several studies have done.

A few studies that did match participants on full-scale IQ found no overall FER deficits in ASD children. For example, Grossman and colleagues (2000) report intact performance in FER in a high-functioning ASD group (although the ASD group did show diminished performance when an incongruent affect word accompanied each face), and Rosset et al. (2008) found intact accuracy in FER among a mix of low- and high-functioning children with ASD. In addition, Loveland and colleagues (1997), using dynamic stimuli, report intact FER in high-functioning children and adolescents with ASD (Loveland et al. were able to match their high-functioning group, but not their low-functioning group, on both verbal and nonverbal mental age). In another study (Gepner et al. 2001), no overall differences emerged between young children with ASD and young TD children in matching 2-second video clips (including still, dynamic, or strobe conditions) to photographs of faces by emotion. Overall, the evidence is mixed on whether there is a general FER deficit in children with ASD, and tighter matching of groups in future studies is warranted. Both discrepancies in age and discrepancies in verbal, nonverbal, or full-scale IQ between groups could affect findings above and beyond differences related to social deficits in ASD, and future studies should have separate groups matched for as many of these variables as possible.

Also potentially important is the cognitive profile of the control group, particularly in studies of low-functioning ASD. In these studies, an ASD group is often matched to an intellectually disabled (ID) control group on chronological age in addition to IQ. Importantly, some etiologies of intellectual disability are associated with diminished FER—for example, there is some evidence for impaired processing of fearful expressions in Down syndrome relative to mental age (Wishart et al. 2007)—while other etiologies (i.e., Williams syndrome) are sometimes associated with superior FER relative to mental age (Riby et al. 2008). Most studies that use an ID control group include individuals with Down syndrome and/or unknown etiology. Both intact (Loveland et al. 1997) and diminished (Celani et al. 1999) FER in low-functioning ASD groups has been found in comparison to controls with Down syndrome. Whereas Loveland and colleagues' stimuli were videos of people speaking, Celani et al. presented single static expressions for a shorter period of time, which may account for different findings in these two studies. Further examination is needed to determine whether, and to what extent, the etiology of intellectual disability in control subjects affects findings regarding FER in low-functioning ASD.

Table 1 Behavioral facial emotion recognition studies in autism spectrum disorders

Study	Participant groups (ASD functioning level, diagnostic measures, mean age)	Matching procedure	FER tasks	Reported FER Deficits in ASD group and between-group p-value and Effect Sizes
Hobson (1986)	LF DSM-III 23 autism (14.6) Group 1: 23 TD (7.25) Group 2: 11 ID (14.0) Group 3: 15 TD (7.1)	Groups 1 and 2: Individually for NVMA Group 3: Individually, TD CA to autism VMA	Matching drawn or photographed facial expression to videotaped gestures, vocalizations, and context expressing 4 basic emotions[a] + neutral	Global (*ps*<.01-.05); performance correlated with VMA and NVMA
Braverman et al. (1989)	LF DSM-III 15 PDD (10.75) 15 TD VMA-matched (5.3) 15 TD NVMA-matched (6.2)	Group-wise for VMA or NVMA	Matching and labeling 4 basic facial emotions; comprehension of emotion labels; Object matching control task	Matching and comprehension: ASD < NVMA-matched controls (d=0.85, *ps*<.05); performance correlated with MA, social behavior, and play
Macdonald et al. (1989)	HF ICD-10 10 autism (all male, 27.2) 10 NT (26.2)	Individually for age and PIQ; NT subjects had higher VIQ	Matching facial expression to context and labeling facial emotions (4 basic emotions + neutral)	Matching (d=1.47, p<.01) and Labeling (d=1.57, p<.02)
Tantam et al. (1989)	HF 10 autism (12.1) 10 TD (12.2)	Individually for age and PIQ; TD had higher VIQ	Finding odd face (person or expression) and labeling facial expression (inverted and upright) with 6 basic emotions; object labeling control task	Finding odd face (d=2.12) and labeling expression in upright face (d=1.0), controlling for VIQ (*ps*<.05)
Ozonoff et al. (1990)	LF CARS 14 ASD (6.4) 14 MLU-matched TD (3.0) 13 NVMA-matched TD (4.1).	Group-wise for MLU or NVMA	Sorting faces by identity/emotion (happy and sad); cross-modal visual/auditory processing task (happiness, sadness, anger); Matching faces by emotion; non-affective control tasks	ASD < NVMA-matched group only: *d*s=1.10-1.19, *ps*=.003-.009
Prior et al. (1990)	LF and HF DSM-III 20 autism (9.9) 20 ID and TD (10.0)	Individually by age, and VMA	Matching 4 basic facial emotions to sounds, gestures, and context; Object control task and false belief tasks	None; success predicted by verbal ability and false belief performance for both groups
Capps et al. (1992)	HF DSM-III 18 HFA (12.5) 14 TD (12.0)	Group-wise by FSIQ, and age	Labeling simple (happy, sad) and complex (proud, embarrassed) facial emotions	Equal accuracy, but response latency and prompt frequency greater for complex emotions, (*d*s=0.87-1.32, ps=.002-.01)
Fein et al. (1992)	LF DSM-III-R 15 PDD/ autism (12.7) 15 VMA matched TD (5.0) 15 NVMA matched TD (5.5)	Group-wise for VMA and NVMA	Matching 4 basic facial emotions to social context; non-social object-matching control task	None, but imbalance in context and object tasks compared to NVMA-matched group; face-matching performance correlated with adaptive behavior, age, and ability

Table 1 (continued)

Study	Participant groups (ASD functioning level, diagnostic measures, mean age)	Matching procedure	FER tasks	Reported FER Deficits in ASD group and between-group p-value and Effect Sizes
Feldman et al. (1993)	LF DSM-III-R 12 boys with autism (5.3) 12 TD boys (5.25)	Individually for age; subjects with autism had lower IQ	Matching emotions (sad, happy, or angry) from videotapes of children interacting followed by static expression	Global; d=1.13, p<.002; intact performance on a control task
Davies et al. (1994)	HF and LF DSM-III-R Exp. 1: 10 HFA/AS (14.9) 10 LFA (13.9) 10 TD (14.7) 10 ID (13.7)	Exp. 1: Individually (HFA/AS with TD controls and autism with ID controls) for age and verbal ability	Exp. 1: Multi-dimensional matching of angry, sad, and surprised facial expressions,	Exp. 1: Emotion and control tasks: HFA/AS < TD (d= 0.37, p<.005); LFA=ID
	Exp. 2: 9 HFA/AS 11 TD 10 LFA 20 ID (mean ages of all groups similar to Exp. 1)	Exp. 2: Group-wise (same groups compared) for age, covarying verbal ability in analysis	Exp. 2: matching emotional expression with identity change; non-facial control tasks in both experiments	Exp. 2: same results (d=0.76, p<.05)
Bormann-Kischkel et al. (1995)	HF DSM-III-R 41 HFA (14.4) 41 TD (13.4) (38 DD and 3 TD)	Individually for age and NVIQ	Categorization of faces expressing 6 basic emotions, excited, calm, and sleepy; Color categorization control task	Global, driven by surprise, scared, and angry (p=.01); intact performance on control tasks
Baron-Cohen et al. (Exp. 3, 1997)	HF DSM-IV, ICD-10 16 ASD (28.6) 16 NT (30.0)	Group-wise for age and ability (IQ for ASD, NART for NT)	Labeling basic and complex emotions from whole face, eyes alone, or mouth alone	Complex emotions only, esp. with eyes alone
Loveland et al. (1997)	HF and LF DSM-IV 17 LFA (15) 18 HFA (12) 18 ID (15) (15 DS, 3 unknown) 23 TD (9) Large age ranges within each group	LFA and ID group-wise on age, VMA; HFA and TD group-wise on VMA, NVMA; age and intelligence covaried	Labeling dynamic facial emotions expressed (angry, happy, sad, surprised, and neutral) verbally, nonverbally, or both; explicit/animate, explicit/flat, implicit/animate, implicit/flat, neutral/animate, neutral/flat conditions	None; effect of intellectual ability only

Celani et al. (1999)	LF DSM-III-R BSE 10 autistic (12;7) 10 DS (12;3) 10 TD (6;3)	Individually for VMA (DS for age as well)	Delayed matching (presentation 750 ms) of faces on emotion (happy, sad, or wry); sorting valence of facial expression (happy or neutral); facial identity tasks	Both facial expression subtests compared to TD and DS (ds=1.07-2.52, ps<.001–.05); facial expression < identity (opposite pattern from controls)
Buitelaar et al. (1999)	HF DSM-IV 20 autism (12.5) 20 PDD-NOS (12.4) 20 non-ASD psychiatric disorder: ADHD, conduct disorder, and dysthymia (12.3) 20 TD (10.5)	Clinical groups matched case-by-case for age and VIQ, TD group not matched and younger	Matching facial emotion and social context with 4 basic simple and complex emotions (surprise, shame, disgust, contempt) Memory control tasks;	Autism/PDD-NOS < psych disorder only when FER tasks analyzed as composite ($p<.05$); autism = PDD-NOS = ADHD performance; verbal memory and PIQ predict performance
Grossman et al. (2000)	HF ICD-10 13 AS (11.8) 13 TD (11.5)	Group-wise for age, IQ, and VIQ (PIQ higher in TD group)	Labeling 5 basic facial emotions paired with matching, mismatching, or irrelevant words	Mismatching emotion word condition only ($d=0.95$, $p<.01$)
Adolphs et al. (2001)	HF ADI 5-8 HFA subjects per task (21-23) 18-47 NT per task (19-56) data from 3-8 subjects with amygdala damage from previous studies per task (47-53)	No matching	Discriminating facial emotion intensity; Labeling 6 basic emotions; Social judgment of faces; Social judgment from lexical stimuli	None, but HFA and amygdala damaged subjects judged faces as more trustworthy
Gepner et al. (2001)	LF DSM-IV 13 autism (69.4 months) 13 TD (40.7 months)	Group-wise for developmental age (Brunet-Lezine scale)	Matching of facial expression in emotional (happiness, surprise, sadness, and disgust) and non-emotional conditions on 2-second video sequence to photograph; still, dynamic, and strobe conditions	None; task performance improved with age in TD group, but not in ASD group
Teunisse and de Gelder (2001)	HF DSM-III-R 17 autism (21.3) 48 NT (20.9); 24 completed angry-sad and 24 completed 2 other continua	Group-wise for age	Discrimination task with three morphed continua: angry-sad, happy-sad, and angry-afraid; Labeling emotion with same stimuli shown individually	Intact identification, but no peak in discrimination task and slower RT at category boundary; in ASD, slope of identification function correlated with social IQ (Social Interpretation List and WAIS Picture Arrangement)
Gross (2004)	LF Exp 1: 27 autism (7.7) 28 LD/PDD (7.3) 26 ID (9.1) 27 non-LD, non-ID clinical controls (7.9) Exp. 2: 18 autism, 9 LD/PDD, 12 ID, 9 non-LD, non-ID clinical controls (mean ages similar to Exp. 1)	Group-wise for age	Exp. 1: Emotion word comprehension task with human, orangutan, and dog faces (happy, sad, angry, surprised, and neutral) Exp 2: Same stimuli, whole-face, upper face, and lower face conditions	Global (ps<.01); error patterns suggest greater focus on lower portions of face

Table 1 (continued)

Study	Participant groups (ASD functioning level, diagnostic measures, mean age)	Matching procedure	FER tasks	Reported FER Deficits in ASD group and between-group p-value and Effect Sizes
Robel et al. (2004)	HF DSM-IV 20 autism/PDD-NOS (8.4) 20 TD (7.9)	Group-wise for age	Minnesota Test of Affective Processing (MNTAP): Emotion naming, emotion matching (fear, surprise, happy, and sad) and identity tasks	None, but impaired discrimination of facial identity
Castelli (2005)	LF and HF 20 ASD (12.3) 20 TD (9.2)	4 Sub-groups for VIQ in ASD group matched to sub-groups with equivalent chronological age in TD group	Matching 6 basic mixed facial emotions with varying intensity levels; Labeling emotion from prototype and mixed facial expressions	None
Dyck et al. (2006)	DSM-IV, SCQ, ADI-R LF and HF 30 autism (23 boys, 8.5) 24 ID (12 boys, 11.56) 449 TD (220 boys, 8.7)	No matching	Labeling 6 basic emotions + contempt and neutral from faces morphing in identity and emotion simultaneously, and from vocal cues	Emotion recognition composite more strongly correlated with verbal comprehension and expressive language in autism than in TD group
Lindner and Rosen (2006)	HF ASDS, PDD Checklist 14 AS (10.2) 16 TD (10.2)	Group-wise for age, sex ratio, and PPVT score	Perception of Emotion Test: decode emotional expressions through dynamic and static facial expression, prosody, verbal content, and all modalities	Static (N^2=.24, d=0.88, p<.05) and dynamic (N^2=.14, d=0.70, p<.01) facial expression and prosody
Ashwin et al. (2007)	HF ICD-10 13 male HFA/AS (31.2), 13 male TD (25.6)	Group-wise for age and FSIQ	Labeling 6 basic facial emotions	Anger, fear, and disgust (ds=0.94-1.59, ps<.001-.01)
Boraston et al. (2007)	HF ADOS 11 ASD (36.7) 11 NT (33.8)	Group-wise for age, VIQ, and PIQ	Identifying 4 basic emotions from abstract animations involving shapes (exp. 1); Labeling emotions from faces	Sadness in both tasks; Animations: (d=1.26, p=.01) Faces: d=1.34, p=.01); Degree of impairment correlated with social interaction symptoms on ADOS
Humphreys et al. (2007)	HF ADOS ADI-R 20 HFA (24.0) 18 NT (28.0)	Group-wise for age, FSIQ, VIQ, and PIQ	Facial expression megamix (labeling prototype expression from all possible blends of 6 basic emotions with varying proportions of each)	Global, driven by fear (p=.006); Difficulty with fear correlated with ADOS Communication Score
Rutherford and McIntosh (2007)	HF ADOS 10 HFA (22.2) 10 NT (20.1)	Group-wise for FSIQ and education	Matching artificial images of faces (varying levels of exaggeration) to prototypical displays of 6 basic emotions	More likely to choose exaggerated facial expressions as realistic for all emotions except surprise (ds=0.91-2.01, ps<.0005–.035)
Tardif et al. (2007)	LF DSM-IV CARS 12 autism (10.4)	Group-wise for sex ratio and either VMA or NVMA	Matching dynamic facial expression (happy, sad, surprised, or disgusted) to static photograph, under silent or with congruent audio and dynamic (slow-normal) speed or static conditions	Global (p<.0003); for autism group, slow dynamic condition and non-emotional facial expressions >other conditions; overall performance negatively correlated with symptom severity

	12 VMA-matched TD (5.1) 12 NVMA-matched TD (6.1)			
Clark et al. (2008)	HF ADI-R or ADOS 15 HFA (26.0) 10 dyslexic (21.6) 10 TD (19.7)	Group-wise for verbal ability	Labeling emotions (happy or angry), gender, or category (object or animal) from face and object stimuli presented for 15 or 30 ms	30 ms condition for emotion judgment (d=4.56, p <.005): ASD: 15 ms=30 ms performance; TD: 15 ms <30 ms performance
Gross (2008)	LF DSM-IV CARS 18 autism (9.5) 18 ID (12.0), unknown 18 Lang. Delay (9.0) 18 TD (6.8)	PIQ, receptive and expressive language	Matching facial expressions (happy, sad, and angry; wrong answers were mismatched blends)	Global, and less affected by inversion than TD and LD N^2=.15, p<.01
Grossman and Tager-Flusberg (2008)	HF DSM-IV ADI-R, ADOS Exp. 1: 25 HFA (13.6) 25 TD (14.1)	Group-wise for age, VIQ, PIQ, and receptive vocabulary	Exp. 1: Implicit processing of pseudo-dynamic expressions and visual speech: recreate sequences of happy, sad, disgust, and fear expressions, and 4 words	Exp. 1: Emotion task (p=.002); Superior in speech task;
	Exp. 2: 22 HFA (13.9) 22 TD (14.2)		Exp. 2: Same tasks, eyes obscured	Exp. 2: No group differences
Homer and Rutherford (2008)	HF 8 HFA males (19.5) 12 NT community male controls 12 NT male undergraduates (19.8)	Group-wise for age, FSIQ, VIQ, and PIQ	Delayed matching followed by categorization of eight series of morphed facial expression continua	Higher RTs in ASD (p<.01), but delayed matching performance predicted categorization, indicating intact categorical processing
Katsyri et al. (2008)	HF DSM-IV ICD-10 ASSQ, ADI-R, ADOS 20 AS (32.8) 20 NT (31.6)	Group-wise for age, PIQ	Likert-scale discrimination of anger, disgust, fear, and happiness in static/dynamic and none/slight/strong filtering conditions	Strong filtering condition (static and dynamic, p=.04), performance correlated with alexithymia (TAS-20)
Riby et al. (2008)	LF CARS 20 autism (12.0) 20 VMA-matched TD (7.5) 20 NV matched TD (8.8)	Individually for VMA or NV ability	Emotion matching and emotion labeling (happy, sad, angry, and surprise)	Matching task: < both control groups; labeling: < NV matched group, ds=0.36-2.33; Group by task interaction p<.05
Rosset et al. (2008)	HF DSM-IV ADI-R	Group 1: Individually for CA and sex	Labeling emotions (sad, happy, or angry) on upright or inverted human faces, human cartoon faces, and non-human cartoon faces	None, but no inversion effect for human faces (p<.05)
	20 ASD (9.5, 4-15) 20 CA-matched TD (9.6) 20 MA-matched TD (8.0)	Group 2: Individually for MA and sex		

Table 1 (continued)

Study	Participant groups (ASD functioning level, diagnostic measures, mean age)	Matching procedure	FER tasks	Reported FER Deficits in ASD group and between-group p-value and Effect Sizes
Wallace et al. (2008)	HF ICD-10 ADI-R Exp 1: 26 ASD (32.0) 26 NT (31)	Group-wise for age and nonverbal ability	Exp. 1: Labeling 6 basic emotions from inverted and upright faces	Exp. 1: Upright (p<.0001) and inverted (p<.05) emotion identification; Language ability positively correlated with recognition, regardless of orientation;
	Exp 2: 15 ASD (30.0) 15 NT (30.0)		Exp. 2: Labeling 6 basic emotions from eyes or mouth only, nose and either eyes or mouth, and all 3 features	Exp. 2: Recognition of fear from eyes and disgust from mouth/nose (ds=0.87-1.60, ps<.001–<.05)
Wright et al. (2008)	HF ICD-10, some ADI-R, ADOS 35 HFA/AS (11.3) 35 TD (11.5)	Group-wise for age, VIQ, and PIQ	Labeling 6 basic facial emotions and occupation with and without context	Angry without context (d=0.52, p=.034)
Akechi et al. (2009)	HF ASQ Exp. 1: 14 ASD (12.1) 14 TD (11.9)	Group-wise for FSIQ, VIQ, and PIQ	Exp. 1: Discriminating angry and fearful expressions with direct or averted gaze	None, but higher RTs for expressions with congruent motivational eye gaze for whole-face and eyes only (N^2=.18, p=.026);
	Exp. 2: 10 ASD (12.4) 10 TD (11.3)		Exp. 2: Same task with only upper face visible	
Kuusikko et al. (2009)	HF ICD-10, ADI-R, ADOS 26 HFA (13.7) 31 AS (13.3) 33 TD (14.5) Age range in ASD groups 9–24	No matching	Labeling 6 basic emotions and blended emotions from eyes	Global, identified ambiguous blends as negatively valenced more often; For blended emotions, older ASD (>12) > younger ASD
Rump et al. (2009)	HF ADOS-G Exp. 1: 19 HFA (6.4) 18 TD (6.0)	Exp. 1: Group-wise for age and VMA	Matching 4 basic emotions from briefly presented videos with varying subtlety	Exp. 1: Global, driven by anger and fear (d=1.11, p<.01)
	Exp. 2: 26 HFA children (10.5, 24 HFA adolescents (15.0), 21 HFA adults (27.0); 23 TD children (10.3), 25 TD adolescents (14.6), 24 NT adults (28.3)	Exp. 2: Group-wise for age, FSIQ, VIQ, and PIQ		Exp. 2: improvement with age <TD; significant deficit in adults only for angry, disgusted, and surprised
Golan et al. (2010)	HF ADI-R 20 ASD with intervention (5.6)	Group-wise for age and verbal ability	Emotional vocabulary and situation-emotion matching (3 levels of generalization) before and after 4 weeks of *Transporters* (emotion exposure) intervention or control intervention; basic and complex emotions trained/	At baseline, global (ds=1.11-1.51, p<.001-.002); Intervention group = TD performance at Time 2

	18 ASD w/o intervention (6.2) 18 TD w/o intervention (5.4)		tested	
Law Smith et al. (2010)	HF DSM-IV, ADOS, ADI-R 21 ASD males (15.3) 16 TD males (14.7)	Group-wise for VIQ and PIQ	Labeling dynamically presented basic emotions of varying intensity	Global, driven by anger, surprise, and disgust; disgust recognition correlated with age in ASD only
Philip et al. (2010)	HF DSM-IV, ADOS (not all met ADOS criteria) 23 ASD (32.5) 23 NT (32.4)	Group-wise for age (higher IQ in NT group, but results equivalent with sub-groups matched for IQ)	Matching and labeling prototype facial emotions and emotions differing in intensity	Global, driven by angry, sad, and fear; correlations between FER, recognizing emotions from voice and body movement, and social judgments from facial stimuli; ADOS-negative participants showed similar, but less pronounced impairment

Only studies with a control group included in tables

Groups matched for sex ratio unless otherwise indicated

ADHD Attention Deficit Hyperactivity Disorder, *ADI* Autism Diagnostic Interview, *ADOS* Autism Diagnostic Observation Schedule, *AS* Asperger's Syndrome, *ASD* Autism Spectrum Disorder, *ASDS* Asperger's Syndrome Diagnostic Scale, *ASQ* Autism Screening Questionnaire, *BSE* Behavioral Summarized Evaluation Scale, *CA* Chronological Age, *CARS* Childhood Autism Rating Scale, *DD* Developmentally Disabled, *DS* Down Syndrome, *DSM* Diagnostic and Statistical Manual, *FER* Facial Emotion Recognition, *FSIQ* Full-Scale IQ, *FXS* Fragile X Syndrome, *HF* High-Functioning, *HFA* High-Functioning Autism, *ICD* International Classification of Diseases, *ID* Intellectually Disabled, *LF* Low-Functioning, *MA* Mental Age, *MCDD* Multiple Complex Developmental Disorder, *NART* National Adult Reasoning Test, *NVMA* Non-verbal Mental Age, *MLU* Mean Length of Utterance, *NT* Neurotypical, *PDD* Pervasive Developmental Disorder, *PDD-NOS* Pervasive Developmental Disorder-Not Otherwise Specified, *PIQ* Performance IQ, *RT* Reaction Time, *SCQ* Social Communication Questionnaire, *TD* Typically Developing, *ToM* Theory of Mind, *VIQ* Verbal IQ, *VMA* Verbal Mental Age

[a] Unless otherwise indicated, 4 basic emotions include happy, sad, angry, and afraid; 5 basic emotions also include surprise, and 6 basic emotions also include disgust

Table 2 Behavioral facial emotion recognition studies in autism spectrum disorder—condensed

Study	Participant groups (ASD functioning level, mean age	Matching procedure	FER tasks	Basic emotion deficit in ASD?
Hobson (1986)	LF 23 autism (14.6) Group 1: 23 TD (7.25) Group 2: 11 ID (14.0) Group 3: 15 TD (7.1)	1 and 2: Individually for NVMA 3: Individually, TD CA to autism VMA	Matching	Yes
Braverman et al. (1989)	LF 15 PDD (10.75) 15 TD VMA-matched (5.3) 15 TD NVMA-matched (6.2)	Group-wise for VMA or NVMA	Matching, labeling, comprehension	Yes, matching and comprehension
Macdonald et al. (1989)	HF 10 autism (all male, 27.2) 10 NT (26.2)	Individually for age and PIQ; NT subjects had higher VIQ	Matching, labeling	Yes, both tasks
Tantam et al. (1989)	HF 10 autism (12.1) 10 TD (12.2)	Individually for age and PIQ	Oddball, labeling, inverted and upright	Yes, upright condition
Ozonoff et al. (1990)	LF 14 ASD (6.4) 14 MLU-matched TD (3.0) 13 NVMA-matched TD (4.1).	Group-wise for MLU or NVMA	Sorting, cross-modal matching, matching	Yes, < NVMA-matched TD group only
Prior et al. (1990)	LF and HF 20 autism (9.9) 20 ID and TD (10.0)	Individually by sex, age, and VMA	Matching, crossmodal	No
Capps et al. (1992)	HF 18 HFA (12.5) 14 TD (12.0)	Group-wise by gender, FSIQ, and age	Labeling	Yes, RT
Fein et al. (1992)	LF 15 PDD/ autism (12.7) 15 VMA matched TD (5.0) 15 NVMA matched TD (5.5)	Group-wise for VMA and NVMA	Matching to context	No
Feldman et al. (1993)	LF 12 boys with autism (5.3) 12 TD boys (5.25)	Individually for age; subjects with autism had lower IQ	Matching	Yes
Davies et al. (1994)	HF and LF Exp. 1: 10 HFA/AS (14.9)	Exp. 1: Individually for age and verbal ability Exp. 2: Group-wise for age	Exp. 1 and 2: Matching	Yes, control tasks also

	10 LFA (13.9) 10 TD (14.7) 10 ID (13.7) Exp. 2: 9 HFA/AS 11 TD 10 LFA 20 ID (mean ages of all groups similar to Exp. 1)			
Bormann-Kischkel et al. (1995)	HF 41 HFA (14.4) 41 TD (13.4) (38 DD and 3 TD)	Individually for age and nonverbal ability	Matching	Yes
Baron-Cohen et al. (Exp. 3, 1997)	HF 16 ASD (28.6) 16 NT (30.0)	Group-wise for age and ability	Labeling with whole face, eyes alone, or mouth alone;	No
Loveland et al. (1997)	HF and LF 17 LFA (15) 18 HFA (12) 18 ID (15) (15 DS, 3 unknown) 23 TD (9)	LFA and ID group-wise on age, VMA; HFA and TD group-wise on VMA, NVMA	Labeling, dynamic stimuli	No
Celani et al. (1999)	LF 10 autistic (12;7) 10 DS (12;3) 10 TD (6;3)	Individually for VMA	Delayed matching, valence sorting	Yes
Buitelaar et al. (1999)	HF 20 autism (12.5) 20 PDD-NOS (12.4) 20 non-ASD psychiatric disorder: ADHD, conduct disorder, and dysthymia (12.3) 20 TD (10.5)	Clinical groups matched case-by-case for age and VIQ; TD group not matched and younger	Matching, context matching	< psych disorder
Grossman et al. (2000)	HF 13 AS (11.8) 13 TD (11.5)	Group-wise for age, IQ, and VIQ (PIQ higher in TD group)	Labeling with matching, mismatching, or irrelevant words	Yes, mismatching emotion word condition
Adolphs et al. (2001)	HF 5-8 HFA subjects per task (21-23) 18-47 NT per task (19-56) data from 3-8 subjects with amygdala	No matching	Discriminating intensity, labeling, social judgment	No

Table 2 (continued)

Study	Participant groups (ASD functioning level, mean age	Matching procedure	FER tasks	Basic emotion deficit in ASD?
	damage from previous studies per task (47-53)			
Gepner et al. (2001)	LF 13 autism (69.4 months) 13 TD (40.7 months)	Group-wise for developmental age (Brunet-Lezine scale)	Matching, dynamic stimuli	No
Teunisse and de Gelder (2001)	HF 17 autism (21.3) 48 NT (20.9); 24 completed angry-sad and 24 completed 2 other continua	Group-wise for age	Labeling emotion blends	Yes, RT, and deficient categorical processing
Gross (2004)	Relatively HF (IQ>65) 20 autism (12.5) 20 PDD-NOS (12.4) 20 ADHD, conduct disorder, or dysthymia (12.3) 20 TD (10.5)	Group-wise for age	Exp. 1: Comprehension, human and animal faces Exp 2: Same stimuli, whole-face, upper face, and lower face conditions	Yes, all tasks
Robel et al. (2004)	LF Exp 1: 27 autism (7.7) 28 LD/PDD (7.3) 26 ID (9.1) 27 non-LD, non-ID clinical controls (7.9) Exp. 2: 18 autism, 9 LD/PDD, 12 ID, 9 non-LD, non-ID clinical controls (mean ages similar to Exp. 1)	Group-wise for age	Labeling, matching	No
Castelli (2005)	HF 20 autism/PDD-NOS (8.4) 20 TD (7.9)	4 Sub-groups for VIQ in ASD group to chronological age in TD group	Matching, labeling, with prototype, varying intensity, and blends	No
Lindner and Rosen (2006)	LF and HF 20 ASD (12.3) 20 TD (9.2)	Group-wise for age, sex ratio, and PPVT score	Matching, dynamic and static	Yes, all
Ashwin et al. (2007)	DSM-IV, SCQ, ADI-R LF and HF 30 autism (23 boys, 8.5) 24 ID (12 boys, 11.56) 449 TD (220 boys, 8.7)	Group-wise for age and FSIQ	Labeling	Yes

Boraston et al. (2007)	HF 14 AS (10.2) 16 TD (10.2)	Group-wise for age, VIQ, and PIQ	Labeling	Yes
Humphreys et al. (2007)	HF 13 male HFA/AS (31.2), 13 male TD (25.6)	Group-wise for age, FSIQ, VIQ, and PIQ	Labeling, emotion blends	Yes
Rutherford and McIntosh (2007)	HF 11 ASD (36.7) 11 NT (33.8)	Group-wise for FSIQ and education	Matching computer-generated exaggerated expressions to prototypical	Yes
Tardif et al. (2007)	HF 20 HFA (24.0) 18 NT (28.0)	Group-wise for sex ratio and either VMA or NVMA	Matching, static and varying dynamic speed	Yes, all conditions
Clark et al. (2008)	HF 10 HFA (22.2) 10 NT (20.1)	Group-wise for verbal ability	Labeling, 15-30 ms presentation	Yes, 30 ms condition
Gross (2008)	LF 12 autism (10.4) 12 VMA-matched TD (5.1) 12 NVMA-matched TD (6.1)	PIQ, receptive and expressive language	Matching (wrong answers were mismatched blends)	Yes
Grossman and Tager-Flusberg (2008)	HF 15 HFA (26.0) 10 dyslexic (21.6) 10 TD (19.7)	Group-wise for age, VIQ, PIQ, and receptive vocabulary	Exp. 1: Recreate pseudo-dynamic expressions of emotion Exp. 2: Same tasks, eyes of stimuli obscured	Exp. 1: Yes Exp. 2: No
Homer and Rutherford (2008)	LF 18 autism (9.5) 18 ID (12.0), unknown 18 Lang. Delay (9.0) 18 TD (6.8)	Group-wise for age, FSIQ, VIQ, and PIQ	Delayed matching, categorization of emotion blends	Yes, RT, but intact categorical processing
Katsyri et al. (2008)	HF Exp. 1: 25 HFA (13.6) 25 TD (14.1) Exp. 2: 22 HFA (13.9) 22 TD (14.2)	Group-wise for age, PIQ	Likert-scale discrimination; stimuli vary in static vs. dynamic and level of filtering	Yes, strong filtering conditions
Riby et al. (2008)	HF 8 HFA males (19.5) 12 NT community male controls 12 NT male undergraduates (19.8)	Individually for VMA or NV ability	Matching, labeling	Matching task: < both control groups; Labeling: < NV matched TD group,
Rosset et al. (2008)	HF 20 AS (32.8) 20 NT (31.6)	Group 1: Individually for CA and sex Group 2: Individually for MA and sex	Labeling	No

Table 2 (continued)

Study	Participant groups (ASD functioning level, mean age	Matching procedure	FER tasks	Basic emotion deficit in ASD?
Wallace et al. (2008)	LF 20 autism (12.0) 20 VMA-matched TD (7.5) 20 NV matched TD (8.8)	Group-wise for age and nonverbal ability	Exp. 1: Labeling, inverted or upright Exp. 2: Labeling with diff. parts of face obscured	Exp. 1: Yes, both conditions Exp. 2: Yes
Wright et al. (2008)	HF 20 ASD (9.5, 4-15) 20 CA-matched TD (9.6) 20 MA-matched TD (8.0)	Group-wise for age, VIQ, and PIQ	Labeling, with and without context	Yes, angry without context
Akechi et al. (2009)	HF Exp 1: 26 ASD (32.0) 26 NT (31) Exp 2: 15 ASD (30.0) 15 NT (30.0)	Group-wise for FSIQ, VIQ, and PIQ	Exp. 1: Discriminating angry and fearful expressions with direct or averted gaze Exp. 2: Same task with only upper face visible	Yes, RT for angry-direct and fearful-averted for whole-face and eyes only (N^2=.18, p=.026);
Kuusikko et al. (2009)	HF 35 HFA/AS (11.3) 35 TD (11.5)	No matching	Labeling, prototype and blended	Yes, both conditions
Rump et al. (2009)	HF Exp. 1: 14 ASD (12.1) 14 TD (11.9) Exp. 2: 10 ASD (12.4) 10 TD (11.3)	Exp. 1: Group-wise for age and VMA Exp. 2: Group-wise for age, FSIQ, VIQ, and PIQ	Matching, brief presentation, varying intensity	Exp. 1: Yes Exp. 2: Adults: yes; Children: No
Golan et al. (2010)	HF 26 HFA (13.7) 31 AS (13.3) 33 TD (14.5) Age range in ASD groups 9-24	Group-wise for age and verbal ability	Emotion vocabulary and situation-emotion matching	Baseline: Yes, intervention group = TD performance at Time 2
Law Smith et al. (2010)	HF Exp. 1: 19 HFA (6.4) 18 TD (6.0) Exp. 2: 26 HFA children (10.5, 24 HFA adolescents (15.0), 21 HFA adults (27.0); 23 TD children (10.3), 25 TD adolescents (14.6), 24 NT adults (28.3)	Group-wise for VIQ and PIQ	Labeling, dynamic presentation, varying intensity	Yes

Philip et al. (2010)	HF 20 ASD with intervention (5.6) 18 ASD w/o intervention (6.2) 18 TD w/o intervention (5.4)	Group-wise for age (higher IQ in control group, but results equivalent with sub-groups matched for IQ)	Matching, labeling, with varying intensities	Yes
Behavioral results from eye-tracking/imaging studies				
Dalton et al. (2005) (Study 1)	LF and HF 14 autism (15.9) 12 TD (17.1)	Group-wise for age	Discriminating emotional and neutral faces, direct and averted gaze	Yes, gaze-direct faces
Neumann et al. (2006)	HF 10 autism (23.0) 10 NT (28.0)	Group-wise for IQ and age	Labeling whole “Bubbles” faces, upright and inverted	No
Spezio et al. (2007a and b)	HF 9 HFA (23.0) 10 NT (28.0)	Group-wise for age, VIQ, PIQ, and FSIQ	Labeling whole “Bubbles” faces	No
Corden et al. (2008)	HF 21 AS (33.0) 21 NT (32.0)	Individually for age, VIQ, PIQ, and visual perception	Labeling	Yes
Rutherford and Towns (2008)	HF 11 ASD (25.67) 11 TD (25.6)	Group-wise for age, IQ, and education	Labeling	No
Bal et al. (2010)	HF 17 ASD (10.3) 36 TD (11.16)	Group-wise on age, FSIQ, VIQ, and PIQ	Labeling dynamic emotion morphs	Yes, RT (perceptual sensitivity)
Critchley et al. (2000)	HF 9 autism (37.0) 9 NT (27.0)	Group-wise by IQ, education, and occupation	Discriminating happy and angry	Yes
Howard et al. (2000)	HF 10 HFA (16-40) 10 TD	Group-wise for age and VIQ	Labeling	Yes
Hall et al. (2003)	HF 8 ASD (20-33) 8 NT	Group-wise for nonverbal IQ and age	Labeling	Yes
Hubl et al. (2003)	Relatively HF 10 ASD (27.7) 10 NT (25.3)	Group-wise for age	Identifying happy	Yes, RT

Table 2 (continued)

Study	Participant groups (ASD functioning level, mean age	Matching procedure	FER tasks	Basic emotion deficit in ASD?
Ogai et al. (2003)	HF 5 autism (21.8) 5 NT (23.0)	Group-wise for age and IQ	Labeling	No
Piggot et al. (2004)	HF 14 ASD (13.1) 10 TD (14.4)	Group-wise for age and IQ	Matching, labeling	Yes, RT in matching
Wang et al. (2004)	HF 12 ASD (12.2) 12 TD (11.8)	Group-wise for age and VIQ	Matching and labeling	Marginal in matching
O'Connor et al. (2005)	HF 15 AS adults (24.6) 15 NT adults (24.8) 15 AS children (11.6) 15 TD children (11.2)	Group-wise for age	Labeling	Adults: yes Children: no
Dziobek et al. (2006)	HF 17 AS (41.4) 17 NT (40.2)	Group-wise for age, education, and IQ	Labeling	Yes
Loveland et al. (2008)	HF 5 ASD (18.25) 4 TD (17.6)	Group-wise for age, VIQ, PIQ	Identifying incongruent and congruent audio-visual representations of emotions	No
Wicker et al. (2008)	HF and LF 12 ASD (27.0) 14 NT (23.4)	Group-wise for age	Discriminating angry and happy	No
Wong et al. (2008)	HF 10 HFA (8.5) 12 TD (8.5)	Group-wise for age and nonverbal ability	Discriminating emotional or neutral	No
Corbett et al. (2009)	HF 12 autism (9.0, all boys) 15 TD (9.2, 13 m/2f)	Group-wise for age, higher IQ in TD group	Matching	Yes, RT
Dziobek et al. (2010)	HF 27 ASD (42.0) 29 NT (44.9)	Group-wise for age, education, and IQ	Labeling	Yes

Greimel et al. (2010)	HF 15 ASD (14.9) 11 fathers of ASD (47.7) 15 TD (15.0) 9 fathers of TD (43.9)	Group-wise for age, FSIQ, and VIQ (PIQ lower in ASD group)	Labeling, prototype or subtle, and self-judgment of emotional response	Yes, subtle condition
Hubert et al. (2009)	HF 16 ASD (25.5) 16 TD (27.2)	Individually for age, and handedness	Discriminating happy or angry	No

Studies of Adults

In studies of children, FER has typically been assessed using static, prototypical facial expressions as stimuli and recognition accuracy as a dependent variable. In studies of older adolescents and adults with ASD, a wider variety of stimuli (e.g., subtly expressed, blended, or "morphing" expressions) and dependent variables (e.g., reaction time) are found, but mixed results are still reported. In addition, as Table 1 indicates, almost all of these studies of adults involve high-functioning individuals, and are therefore better able to match participants on both age and IQ. Many studies still find reduced accuracy in identifying emotions in adults with ASD, especially for negative emotions (Ashwin et al. 2006; Bal et al. 2010; Corden et al. 2008; Howard et al. 2000; Wallace et al. 2008). Yet in other studies of older and higher-functioning ASD groups, diminished FER is absent (Adolphs et al. 2001; Loveland et al. 2008; Neumann et al. 2006; Ogai et al. 2003; Rutherford and Towns 2008) or much more subtle (Baron-Cohen et al. 1997; Teunisse and de Gelder 2001). Discrepant findings in studies of older adolescents and adults could be attributed to different task demands and dependent variables.

In sum, the demographic issues that may affect the results of behavioral studies of FER in ASD include age and IQ, the effects of which are difficult to examine separately due to the nature of the literature (i.e., few studies involving low-functioning older age groups with ASD). Specifically, potentially more static development of FER in ASD and the difficulties of appropriately matching low-functioning individuals with ASD should be considered when evaluating existing research. Three directions for future research could help to address these issues: 1) matching groups or individuals on both verbal and nonverbal IQ when possible, or including both a verbal IQ- and a nonverbal IQ-matched control group, and 2) carefully documenting any known ID etiology in control groups matched to low-functioning individuals with ASD, and 3) investigating the developmental trajectory of and age-related changes in FER in ASD through additional longitudinal and cross-sectional studies (since findings vary between the few cross-sectional studies that have been conducted). In addition, studies that include larger sample sizes will be better powered to detect group differences, especially considering the heterogeneity of ASD.

Task Demands

Aside from the demographic characteristics of participants, a myriad of variations in experimental tasks might also explain conflicting findings regarding FER in ASD. Yet demographics and task demands cannot be completely separated, as studies with low-functioning and younger individuals understandably use simpler tasks. In most studies involving low-functioning individuals and/or children, tasks involve matching static, prototypical pictures of facial expressions to other emotion-laden stimuli. The types of stimuli used do not appear to have a systematic influence on study results in low-functioning ASD: ASD-related deficits have been found across a wide range of experimental tasks, including matching photographs of facial expressions across identity (Celani et al. 1999), matching videotaped facial expressions to photographs and schematic drawings (Hobson 1986), matching dynamically presented expressions to photographs (Tardif et al. 2007), and even identifying both human and animal faces depicting various emotions (Gross 2004). Conversely, low-functioning individuals have performed equally to controls matched for developmental level or verbal mental age in tasks involving dynamic stimuli (Gepner et al. 2001) and labeling both static emotion blends and prototypical expressions (Castelli 2005). In low-functioning ASD, demographic factors, especially the relative age and ability of the control group, might explain more of the variance in findings than the task used.

The choice of tasks seems to be a more important factor in high-functioning ASD, likely because more complex tasks can be used with this population. When task demands are taken into account, the evidence does not support a *general* FER accuracy deficit in high-functioning adolescents and adults with ASD. Although some studies do show such a deficit (Dalton et al. 2005; Macdonald et al. 1989; Tantam et al. 1989) others do not (Baron-Cohen et al. 1997; Capps et al. 1992; Homer and Rutherford 2008), at least when analysis is limited to the six basic emotions. High-functioning individuals do appear to have more difficulty recognizing complex emotions, such as guilt, shame, and envy (e.g., Baron-Cohen et al. 1997). In contrast to some of the research involving individuals with low-functioning ASD, non-significant group differences cannot often be explained by a lower age or lower nonverbal ability in the control group, although some might be accounted for by ceiling effects in both groups. Most often, studies of high-functioning ASD have found abnormal behavioral performance only under specific conditions: when faces were presented with incongruent emotion labels (Grossman et al. 2000); when faces were shown for very brief durations (e.g., 30 ms; Clark et al. 2008); when expressions were artificially exaggerated—in one study, young adults with ASD were more likely to judge computer-generated exaggerated facial expressions as representative of a given emotion than controls (Rutherford and McIntosh 2007); or when an approach-oriented facial expression (anger) was paired with direct gaze and an avoidance-oriented expression (fear) was paired with averted gaze (Akechi et al. 2009). In another study, adolescents with high-functioning autism had difficulty recreating visual sequences of emotional expressions (Grossman and Tager-Flusberg 2008). Other studies of high-functioning individuals with ASD find deficits with only specific negative emotions, such as sadness (Boraston et al. 2007) or fear (Howard et al. 2000). In sum, when facial-emotion processing is made more difficult (i.e., presenting conflicting information or shortening presentation time) or otherwise manipulated to reveal alternative processing strategies, FER deficits emerge in high-functioning individuals with ASD. Yet, under standard viewing conditions with prototypical facial expressions, at least some of these individuals can identify emotions as well as controls.

Intact FER in some high-functioning samples does not rule out the use of compensatory mechanisms to decode facial emotions in ASD. The specific nature of these compensatory mechanisms might vary between individuals, but one possibility is that individuals with ASD use explicit cognitive or verbally mediated processes to recognize emotions, in contrast to more automatic emotion processing in TD individuals. Thus, higher-functioning individuals with ASD might be able to capitalize on their cognitive and/or linguistic resources to correctly identify facial expressions. In support of this possibility, affect-matching paradigms (e.g., Davies et al. 1994; Piggot et al. 2004; Rump et al. 2009) are more likely than labeling paradigms (e.g., Katsyri et al. 2008; Piggot et al. 2004; Rutherford and Towns 2008) to reveal group differences in FER behavioral performance (although labeling tasks can only be used with higher-functioning individuals, which might also influence these findings). For some high-functioning individuals with ASD, seeing the emotion labels on the screen might facilitate their recognition of facial emotions, especially if they have been formally trained to identify emotions using these labels (a component of many intervention programs for individuals with ASD). Also supporting the idea that individuals with ASD use explicit cognitive mechanisms to recognize emotions, at least in an experimental setting, some evidence suggests that FER task performance is more related to general cognitive ability in ASD than in typical development: for example, studies have found that mental age (Hobson 1986) and receptive and expressive language (Dyck et al. 2006) predict emotion recognition ability in children with ASD, but not TD children.

Explicit cognitive or language-mediated mechanisms might compensate for a less efficient processing style when interpreting emotional faces. Specifically, individuals with ASD might use local, feature-based processing, in contrast to the global, configural-based strategy used by TD individuals (e.g., Behrmann et al. 2006). A local processing bias could also be a compensatory mechanism itself if individuals with ASD are able to memorize the specific features associated with each emotion (although this could impair generalization). Evidence for a general local processing bias in ASD comes from studies documenting superior performance and/or faster reaction times on block design and embedded figures tasks in ASD (Shah and Frith 1993; Keehn et al. 2009). FER tasks have also revealed differences in ASD consistent with more feature-based than configural processing. Some studies have failed to find an inversion effect for faces in ASD (Tantam et al. 1989; Gross 2008), in that those with ASD, in contrast to a control group, identified emotions from inverted faces as well as they did from upright faces. In addition, impaired FER in ASD at low, but not high, spatial frequencies (Katsyri et al. 2008) has been documented. Both findings suggest impaired configural processing of faces in ASD, since configural processing should impair performance when decoding inverted faces, but facilitate accurate emotion recognition even when decoding faces presented in a low spatial frequency. However, at least one study has documented the typical inversion effect in the context of FER within an ASD group (Wallace et al. 2008). Furthermore, a recent study suggests that individuals with ASD are capable of configural face processing, experiencing interference from facial features they are instructed to ignore, at least when processing facial identity (Gauthier et al. 2009). Thus, it is unclear whether a local processing bias for faces exists in all individuals with ASD.

Perhaps related to feature-based processing are findings that individuals with ASD have more difficulty recognizing negative emotions than happiness, which could be recognized by the upturned mouth alone. However, which emotion(s) is most impaired varies between studies, from surprised, scared, and angry (Bormann-Kischkel et al. 1995) to sadness (Boraston et al. 2007) to fear (Humphreys et al. 2007). The specific faces used as models might play a role in these discrepancies. Many studies use face stimuli from Ekman and Friesen's Pictures of Facial Affect Series (Ekman and Friesen 1971), as this measure is well validated and extensively researched. However, even these faces differ somewhat in their encoding of emotion: for example, expressions such as happiness or anger can be expressed with the mouth open or closed. Furthermore, variations in the structural features of individual faces may influence the ease of identifying emotions. These factors could also account for greater difficulty with face-to-face matching than with labeling emotions in ASD. If individuals with ASD overlearn features associated with specific facial emotions, limiting their ability to generalize across faces, then individual encoding differences may be more likely to impair their performance on tasks involving face-to-face emotion matching. For example, if specific features of one face look different from that of another face, individuals with ASD might not be able to generalize the emotion from one face to the other. Intriguingly, young TD children also show improved FER performance in a labeling condition over matching (Russell and Widen 2002), and studies suggest that FER becomes more configural and less feature-based over time in typical development (Herba and Phillips 2004). Taken together, these findings suggest that the mechanisms that allow for efficient face-to-face matching of emotions are later maturing in typical development and perhaps absent in ASD. To address this issue, future studies of FER in ASD could utilize matching tasks that systematically vary similarities in encoding between faces.

Another task manipulation that could reveal different processing styles in ASD involves using dynamic stimuli. Assessing FER through the use of static facial expressions alone may present a problem because these expressions could be learned explicitly in the context of ASD-related therapeutic interventions. A few studies have used dynamic, fully expressed facial emotions, and interestingly, several of these have found no differences between ASD and control groups (Loveland et al. 1997; Gepner et al. 2001), although Gepner et al. also included static stimuli. Indeed, children with ASD have been shown to perform better on a task utilizing *slow* dynamic presentation of full facial expressions than a task that used static photographs of these expressions (Tardif et al. 2007), which suggests that motion, at least when it is slow, improves performance for these individuals. Yet, although dynamic presentations of full facial expressions are more ecologically valid than static presentations, such prototypical expressions are encountered in the real world less frequently than more subtle expressions.

In daily life, people most often encounter subtle facial expressions, and even when individuals with ASD demonstrate intact performance on FER tasks, they are likely to have problems in everyday social interactions. Thus, "morphed" stimuli that depict expressions of differing intensity (morphing from neutral to fully expressive) or mixed expressions (morphing from one emotion to another) may be more sensitive to differences between ASD and control groups than fully expressive faces. Morphed faces may be especially useful for identifying diminished FER in older, high-functioning individuals, who are more likely to have the cognitive resources to accurately identify prototypical expressions, though perhaps through atypical mechanisms.

The few studies that have utilized morphed stimuli report mixed results, but overall suggest diminished FER in ASD. Both Homer and Rutherford (2008) and Teunisse and de Gelder (2001) used mixed facial expressions to examine categorical perception differences between high-functioning adults with ASD and controls, and the former study found no abnormalities in ASD, while the latter study did. However, Homer and Rutherford (2008) found increased reaction times in the ASD group (Teunisse and de Gelder did not report whether there were group differences in reaction times). Another study using blended expressions (Castelli 2005) found no differences between children with ASD at various levels of functioning (mental age ranged from 6-14) and TD controls; however, group matching in this study was not very precise. Later studies using emotion blends have found that high-functioning individuals with ASD exhibit diminished recognition of fear (Humphreys et al. 2007) or difficulty with all emotions (Kuusikko et al. 2009). Recently, three studies have used lower-intensity, but unblended, facial expressions, and reported ASD-related FER deficits in both adolescents (Greimel et al. 2010; Law Smith et al. 2010) and adults (Philip et al. 2010). Researchers have also begun to test participants on sequences of low- to high-intensity emotional face stimuli, creating faces that morph from neutral to fully expressive. These stimuli can be used to measure not only accuracy, but also perceptual sensitivity to emotional expression—the degree of *intensity* required for accurate recognition. For example, Bal and colleagues (2010), using neutral to expressive morphs (15–33 s) found diminished perceptual sensitivity across emotions, the extent of which was correlated with social impairment.

Task demands might explain a great deal of the variations in findings regarding FER in ASD, especially among high-functioning individuals. Depending on the task, some high-functioning individuals may be able to employ cognitive, language-based, or perceptual compensatory mechanisms to succeed in FER tasks, despite abnormal processing of the stimuli. The trend towards more dynamic, complex, and ecologically valid stimuli is encouraging and will be more informative for addressing the real-life difficulties faced by individuals with ASD than the static, prototypical faces used in early studies. Furthermore, studies that use morphing sequences of facial expressions to examine FER in ASD are uncommon, but will likely be important in investigating more subtle differences in FER between individuals with ASD and TD individuals.

Eye-Tracking and Brain-Based Studies

Eye-tracking and brain-based studies of FER in ASD, including (functional) magnetic resonance imaging (f) (MRI), positron emission tomography (PET), and event-related potentials (ERP), are an important complement to the behavioral studies discussed above because they allow researchers to explore not only how quickly and accurately participants can recognize emotions, but also the mechanisms underpinning their emotion decoding. In stark contrast to the behavioral studies that measure subjects' ability to match or label facial expressions, nearly all eye-tracking, neuroimaging, and electrophysiological studies have reported ASD-related abnormalities in FER (see Table 3).

Eye-Tracking Studies

An often-debated face-processing anomaly in ASD concerns the salience and processing of information from the eyes. Many studies show that high-functioning individuals with ASD look less at the eye region of emotionally expressive faces than controls (e.g., Pelphrey et al. 2002; Corden et al. 2008) or do not use information from the upper aspects of the face as effectively during emotion identification (Baron-Cohen et al. 1997; Gross 2008; Spezio et al. 2007a and b). Some studies also find that individuals with ASD rely more on information from the lower portions of the face (i.e., mouth) in FER (Neumann et al. 2006; Spezio et al. 2007a). Yet, other studies indicate that these individuals look at the eyes in proportion to the rest of emotionally-expressive faces as much as controls do (Bal et al. 2010; Hernandez et al. 2009). Another finding in the eye-tracking literature is that individuals with ASD look more towards regions outside the core facial features when decoding emotions (Bal et al. 2010; Hernandez et al. 2009). Although the nature of the differences varies, most FER studies that utilize eye-tracking do find abnormalities in ASD. One of these studies (Neumann et al. 2006) has used computational modeling to suggest that altered fixation patterns in ASD reflect top-down modulation of eye gaze, rather than bottom-up effects of visual saliency (i.e., it is not that mouths are simply more perceptually interesting than eyes). Thus, as a whole, eye-tracking studies suggest that individuals with ASD process emotional faces differently than controls.

Neuroimaging Studies

As a complement to eye tracking, neuroimaging studies can provide information about the neural correlates associated with decoding emotions. In neurotypical individuals, the core brain regions implicated in all types of face processing include the inferior occipital gyri, lateral portion of the fusiform gyrus (especially a region deemed the fusiform face area, or FFA), and posterior superior temporal sulcus (pSTS) (Haxby et al. 2000). Haxby and colleagues (2000) have proposed that processing invariant aspects of the face (i.e., identity) involves relatively greater activation of fusiform regions, whereas processing variable aspects of the faces (e.g., eye gaze, expression) recruits the pSTS to a larger extent. In the case of facial emotion processing,

Table 3 Eye-tracking, brain-based, and autonomic physiological facial emotion recognition studies in autism spectrum disorders

Study	Participant groups (ages in years), diagnostic measures, ASD-group level of functioning	Matching procedure	FER tasks	Findings in ASD, and associated p-values and effect sizes
Eye-tracking studies				
Dalton et al. (2005) (Study 1)	LF and HF DSM-IV, ADI 14 males with autism (15.9) 12 TD males (17.1)	Group-wise for age	Discriminating emotional and neutral faces with direct and averted-gaze faces with eye-tracking and fMRI	Eye tracking/ imaging: Less fixation time on eyes; Eye fixation time correlated with FG and amygdala activation;↑ L. amygdala (p=.02) and OFC (p =.007); ↓ FG, occipital and middle frontal gyri (ds 1.78-2.51; ps<.001); Behavior: ↓ for emotional and gaze-direct faces; ds= 0.83-1.48, ps=.01-.04;
Neumann et al. (2006)	HF DSM-IV/ICD-10, ADI, ADOS 10 autism (23.0) 10 NT (28.0)	Group-wise for IQ and age	Labeling whole faces (6 basic emotions) and "Bubbles" faces (happy or fearful), upright and inverted, with eye-tracking	Eye-tracking: more fixations to mouth in all "Bubbles" faces Behavior: =
Spezio et al. (2007a and b)	HF DSM-IV/ICD-10, ADI, ADOS 9 HFA (23.0) 10 NT (28.0)	Group-wise for age, VIQ, PIQ, and FSIQ	Labeling "Bubbles" faces (fearful and happy) and unfiltered faces (6 basic emotions) with eye-tracking	Eye-tracking: looked more at mouth and made more saccades away from eyes, esp. when information was in eyes; Abnormal saccade direction from L. eye and mouth; Behavior: =
Corden et al. (2008)	HF ADOS 21 AS (33) 21 NT (32)	Individually for age, VIQ, PIQ, and visual perception (DTVP)	Labeling 6 basic emotions with and without eye-tracking	Eye tracking: Less time fixating eyes (p=.02), correlated with poor fear recognition; Behavior: ↓ fear (d=0.95, p<.05) and sad (d=0.40, p<.05)
Hernandez et al. (2009)	HF DSM-IV 22 NT (22.7) 7 autism (24.09)	No matching	Eye-tracking while viewing facial emotions (happy, sad, or neutral) with direct or averted gaze	Looked more at non-core facial regions than TD (p<.001), but still mostly at eyes; No effect of averted gaze
Rutherford and Towns (2008)	HF ADOS 11 ASD (25.67) 11 NT (25.6)	Group-wise for Age, IQ, and education	Labeling basic and complex emotions with eye-tracking	Eye tracking: Looked less at eyes with complex emotions (p=.028); Behavior: =
Bal et al. (2010)	HF ADOS 17 ASD (10.3, 16 m/1f) 36 TD (11.16, 23 m/13f)	Group-wise on age, FSIQ, VIQ, and PIQ	Labeling 6 basic emotions from faces morphing from neutral to expressive (in 15–33 s) with eye gaze, RSA, and heart rate measurement	Eye tracking: Gaze to eyes = to TD, correlated with task accuracy; Behavior: ↓ accuracy for anger (d=0.75, p=.009), ↑ RT for all emotions (p=.015); Accuracy neg. correlated with social impairment; Physiological: At baseline, ↓ RSA (p=.045) and ↑ heart rate (p=.023); RSA neg. correlated with recognition latency

Table 3 (continued)

Study	Participant groups (ages in years), diagnostic measures, ASD-group level of functioning	Matching procedure	FER tasks	Findings in ASD, and associated p-values and effect sizes
Brain-based studies				
Critchley et al. (2000)	HF ICD-10, ADI 9 autism (37) 9 NT (27)	Group-wise by IQ, education, and occupation	Implicit (gender discrimination) and explicit (labeling) facial emotion processing (happy or angry) with fMRI	Imaging: ↓ FFA in explicit processing; ↓ left amygdala and cerebellum in implicit processing (ps <.001–.008); Behavior: ↓
Howard et al. (2000)	HF ADI checklist 10 HFA males (16–40) 10 TD males	Group-wise for age and VIQ	Labeling 6 basic facial emotions; Structural MRI	Imaging: Enlarged amygdala; Behavior: ↓ fear (d= 2.34, p<.05); Emotion recognition and amygdala size unrelated
Hall et al. (2003)	HF DSM-IV 8 ASD (20–33) 8 NT	Group-wise for nonverbal IQ and age	Labeling emotion (happy, sad, surprised, or angry) when viewing and listening to facial emotion stimuli with prosodic voices with PET	Imaging: ↓ IFG and FG; ↑ R. anterior temporal pole, anterior cingulate, and thalamus; Behavior: ↓
Hubl et al. (2003)	Relatively HF (NVIQ>70) ADI-R, ADOS 10 ASD (27.7) 10 NT (25.3)	Group-wise for age	Emotion and gender discrimination with emotional faces (happy, sad, angry, neutral); Viewing scrambled faces; visual search; In fMRI	Imaging: ↓ FG and INS, ↑ MFG and SPL; Behavior: = accuracy, ↑ RT
Ogai et al. (2003)	HF DSM-IV 5 autism (21.8) 5 NT (23.0)	Group-wise for age and IQ	Labeling emotions (happy, disgust, fear, and neutral) in fMRI	Imaging: ↓ MFG with fear; ↓ insula, IFG, and putamen with disgust; Behavior: =
Dawson et al. (2004)	HF DSM-IV, ADI-R, ADOS-G 29 ASD (44.8 months) 22 TD (43.7 months)	Group-wise for age (subgroup for MA also)	ERP when viewing fearful and neutral faces; Social attention task	Equal amplitudes of N300 and NSW to fear and neutral; In TD group, higher amplitudes to fear; Faster N300 in response to fear correlated with social attention task performance
Piggot et al. (2004)	HF DSM-IV, ADI-R, ADOS 14 ASD males (13.1) 10 TD males (14.4)	Group-wise for age and IQ	Emotion match, emotion label, and control tasks in fMRI (fearful, surprised, and angry faces)	Imaging: ↓ FG in matching task when covarying for task RT (p=.008); Behavior: ↑ RT in matching task
Wang et al. (2004)	HF ADI-R, ADOS 12 ASD males (12.2) 12 TD males (11.8)	Group-wise for age and VIQ	Matching and labeling in fMRI (anger and fear); Control shape-matching task	Imaging: ↓ FG (p=.05), but ↑ precuneus (p<.05) during face-emotion matching; Only TD group shows ↑ R. amygdala in matching task (compared to labeling) (p=.04); Behavior: marginally ↓ in matching task
Dalton et al. (2005) (Study 1)	LF and HF DSM-IV, ADI 14 males with autism (15.9) 12 TD males (17.1)	Group-wise for age	Discriminating emotional and neutral faces with direct and averted-gaze faces with eye-tracking and fMRI	Eye tracking/ imaging: Less fixation time on eyes; Eye fixation time correlated with FG and amygdala activation;↑ L. amygdala (p=.02) and OFC (p=.007); ↓ FG, occipital and middle frontal gyri (ds 1.78-2.51; ps<.001); Behavior: ↓ for emotional and gaze-direct faces; ds= 0.83-1.48, ps=.01-.04;

O'Connor et al. (2005)	HF DSM-IV 15 AS adults (24.6) 15 NT adults (24.8) 15 AS children (11.6) 15 TD children (11.2)	Group-wise for age	Labeling 4 basic emotions + neutral with ERP	Brain: adult AS = child AS; Delayed P1 and N170 latencies, smaller N170 amplitudes in adults (ds=0.87-1.59, ps<.05); Behavior: ↓ sad, angry, and neutral in adults only (ds=0.97-1.14, *p*<.001)
Dapretto et al. (2006)	HF DSM-IV ADI-R, ADOS 10 ASD (12.0) 10 TD (12.4)	Group-wise for age and FSIQ	Imitating and passively observing 4 basic facial emotions + neutral in fMRI	Imaging: ↓ IFG, insula and amygdala; ↑ occipital and anterior parietal regions; Activity in IFG negatively correlated with social symptoms (ps<.05)
Dziobek et al. (2006)	HF DSM-IV, ADI-R 17 AS (41.4) 17 NT (40.2)	Group-wise for age, education, and IQ	Labeling 6 basic emotions; Movie for the Assessment of Social Cognition (emotional and non-emotional mental states); Structural MRI	Imaging: no amygdala size differences; Emotion recognition and amygdala size positively correlate in NT, but not ASD; Behavior: ↓
Ashwin et al. (2007)	HF ICD-10 13 HFA/AS males (31.2), 13 NT males (25.6)	Group-wise for age and FSIQ	Implicit Processing of scrambled faces, neutral expressions, low fear expressions, and high fear expressions in fMRI; Facial emotion-labeling task (5 basic negative emotions) outside of scanner	Imaging: ↓ left amygdala and left OFC in response to fear expressions, and ↑ STS and ACC in response to all facial stimuli; No modulated response in FG and MPFC in response to differing intensity of fear; Behavior: ↓
Deeley et al. (2007)	HF ICD-10, DSM-IV ADI or ADOS 9 AS males (34) 9 NT males (27)	Group-wise for FSIQ and VIQ	Viewing neutral, mild, and intense expressions of 4 basic emotions (fear, disgust, happy, and sad) in event-related fMRI	↓ fusiform and extrastriate cortices in response to all emotions; Lack of modulation of these regions to differing intensities of disgust
Pelphrey et al. (2007)	HF ADI-R, ADOS 8 HFA (24.5) 8 NT (24.1)	Group-wise for age and IQ	Viewing fearful, angry, and neutral facial expressions from Ekman series in fMRI; Static neutral, static emotional, dynamic identity morph, and dynamic emotion morph conditions	No modulation of amygdala, FG, and STS in response to dynamic vs. static fearful and angry facial expressions (N^2s=.34-.49, ps<.01); ↓ R. amygdala (*d*=1.59, *p*<.01) and FG for emotion morphs; ↑ R. STS with static emotions (*d*=1.53, *p*<.05)
Loveland et al. (2008)	HF DSM-IV ADI-R, ADOS 5 ASD (18.25) 4 TD (17.6)	Group-wise for age, VIQ, PIQ	Identifying incongruent and congruent audio-visual representations of emotions (happy, angry, fearful, surprise, and disgust) and gender	Imaging: ↓ medial frontal and orbito-frontal regions in emotion congruence—sex congruence contrast; ↑ activation of same regions in opposite contrast (ps<.05); Behavior: =
Wicker et al. (2008)	HF and LF DSM-IV 12 ASD (27.0) 14 NT (23.4)	Group-wise for age	Implicit or explicit emotion processing (angry or happy) in fMRI	Imaging: Abnormal activation of vLPFC and abnormal connectivity between dLPFC and posterior temporal regions; Behavior: =
Wong et al. (2008)	HF DSM-IV, ADI 10 HFA boys (8.5) 12 TD boys (8.5)	Group-wise for age and nonverbal ability	Implicit and explicit emotion processing (happy, angry, and neutral) with ERP and dipole source analysis	Brain: Normal surface ERPs; Weaker/slower ERP responses in visual cortex, FG, and MPFC; Slower/ larger amplitude ERP responses in parietal somatosensory cortices; Larger RH P2 amplitudes to happy than angry or neutral faces; Behavior: =

Table 3 (continued)

Study	Participant groups (ages in years), diagnostic measures, ASD-group level of functioning	Matching procedure	FER tasks	Findings in ASD, and associated p-values and effect sizes
Corbett et al. (2009)	HF DSM-IV ADI or ADOS 12 autism (9.0, all boys) 15 TD (9.2, 13 m/2f)	Group-wise for age, higher IQ in TD group	Matching 4 basic facial expressions + neutral with fMRI	Imaging: ↓ FG (p=.03) and amygdala (p=.046); No group differences in amygdala volume; Behavior: ↑ RT
Dziobek et al. (2010)	HF DSM-IV, ADI-R, AQ 27 ASD (42.0) 29 NT (44.9)	Group-wise for age, education, and IQ	Labeling 6 basic emotions; Structural MRI	Imaging: ↑ local cortical thickness in FG, correlated with FER deficit; No correlation between amygdala volume and FG local thickness; Pos. correlation in controls; Behavior: ↓
Monk et al. (2010)	HF 12 ASD 12 NT 18-40, mean age not reported	Not reported; PIQ>85 for all participants	Attention cueing (implicit FER) task with happy, sad, angry, and neutral faces (neutral as baseline)	Imaging: ↑ R. amygdala with happy and sad; R. amygdala showed ↑ connectivity with vmPFC with happy, ↓ connectivity with MTG with all emotions, and ↓ connectivity with IFG with sad; Behavior: = attention effects
Greimel et al. (2010)	HF DSM-IV, ICD-10, ADOS, ADI 15 ASD boys (14.9) 11 fathers of ASD (47.7) 15 TD boys (15.0) 9 fathers of TD (43.9)	Group-wise for age, FSIQ, and VIQ (PIQ lower in ASD group)	Labeling prototype or subtle emotions (happy and sad) and self-judgment of emotional response to face with fMRI	Imaging: ↓ FG, correlated with social deficits; Less congruent reactions and ↓ IFG in self condition; In ASD subjects' fathers, ↓ amygdala and FG in subtle, other condition; Behavior: ↓ subtle emotions (p<.05)
Autonomic physiological studies				
Hubert et al. (2009)	HF DSM-IV, ASSQ 16 ASD (25.5) 16 NT (27.2)	Individually for age, and handedness	Discriminating emotion (happy or angry) or age from faces or direction of moving object with SCR	Physiological: ↓ SCR in emotion judgment d=0.91, p<.05; Behavior: =

ACC Anterior Cingulate Cortex, *dLPFC* dorso-lateral Prefrontal Cortex, *DTVP* Developmental Test of Visual Perception, *ERP* Event-related Potential, *FFA* Fusiform Face Area, *FG* Fusiform Gyrus, *fMR*I Functional Magnetic Resonance Imaging, *IFG* Inferior Frontal Gyrus, *MFG* Medial Frontal Gyrus, *MPFC* Medial Prefrontal Cortex, *MTG* Medial Temporal Gyrus, *NSW* Negative Slow Wave, *OFC* Orbitofrontal Cortex, *RH* Right Hemisphere, *RSA* Respiratory Sinus Arrythmia, *SCR* Skin Conductance Response, *SPL* Superior Parietal Lobule, *STS* Superior Temporal Sulcus, *vLPFC* ventro-lateral Prefrontal Cortex limbic regions such as the amygdala also tend to be activated. In the literature on both facial identity processing and FER in ASD, decreased fusiform gyrus (FG) activation is a common finding (Hubl et al. 2003; Pierce et al. 2001; Schultz et al. 2000). However, this finding is not a universal one (see Bookheimer et al. 2008), especially when familiar faces are used as stimuli (Pierce and Redcay 2008).

Although many studies of FER report decreased FG activation in ASD (Bolte et al. 2006; Piggot et al. 2004; Wang et al. 2004) relative to control groups, this finding might not relate to emotion processing specifically; it is possible that the FG activation found in controls is associated with identity-level rather than emotion processing. Intriguingly, studies that have combined eye-tracking with fMRI (Dalton et al. 2005) or manipulated gaze to faces during fMRI (Hadjikhani et al. 2004) have shown that individuals with ASD do activate the FG when they look at the eyes. In contrast, Bolte and colleagues (2006) failed to increase FG activity in participants with ASD during an FER task through the use of a facial emotion training program. However, the training program did improve the intervention group's behavioral performance, and activation in the right superior parietal lobule, a region thought to be involved in visuo-spatial skills, increased. These authors suggest that the intervention group may have more effectively utilized compensatory mechanisms to recognize emotions.

If individuals with ASD must use alternative means to recognize emotions, this might be because brain regions involved in pre-conscious aspects of FER fail to activate in ASD. The amygdala is a brain region that responds to even masked emotional faces (Morris et al. 1998; Whalen et al. 1998) in both adults and children (Killgore and Yurgelun-Todd 2010), and a recent MRI diffusion tensor-tracking study (Smith et al. 2009) revealed a pathway connecting the amygdala and FG. Thus, diminished FG activation in ASD could also be related to amygdala dysfunction. Reduced amygdala activity is a common finding in the fMRI literature on both neutral face processing (Hadjikhani et al. 2007) and FER (Ashwin et al. 2007; Dapretto et al. 2006; Pelphrey et al. 2007) in ASD, although some studies have found no group differences in amygdala activity for neutral, familiar (Pierce et al. 2004) or emotional faces (Piggot et al. 2004), and two studies found increased amygdala activity in the ASD group in response to emotional faces (Dalton et al. 2005; Monk et al. 2010). Most importantly, nearly all neuroimaging studies that used an implicit FER task report decreased amygdala activity in the ASD group, suggesting that the amygdala does not function normally during face perception in ASD, at least when participants are not required to attend to the displayed emotion. Notably, the one study that reported increased amygdala activation in ASD during an implicit FER task (Monk et al.) used an attention-cueing paradigm to ensure that participants attended to the faces. The majority of evidence therefore suggests decreased automatic amygdala activation to emotional faces, although this may be due to diminished attention to the faces.

How might amygdala dysfunction affect FER from a developmental perspective? Grelotti and colleagues (2002) have proposed that early amygdala dysfunction in ASD could prevent infants with the disorder from attaching emotional significance to faces and facial expressions, preventing specialization for faces in higher cortical areas such as the FFA. Abnormal structural development of the amygdala has been found in ASD (Howard et al. 2000; Schumann et al. 2004), and two other structural MRI studies, although not related to FER, found that a larger amygdala volume at 3 years of age was associated with more social and communication problems at ages 5-6 years (Munson et al. 2006; Schumann et al. 2009). Amygdala volume has not been directly associated with FER in adults with ASD, though positive correlations have been shown in neurotypical adults (Dziobek et al. 2006). A possible explanation for this finding is that the amygdala plays less of a role in emotion decoding in ASD than in typical development. Furthermore, a recent study indirectly implicates altered amygdala-fusiform connectivity in an ASD-related FER deficit: in adults with ASD, a slight negative correlation between local cortical thickness in the FG and amygdala volume was found, whereas controls showed a strong positive correlation. In addition, FG local thickness was negatively correlated with FER in the ASD group (Dziobek et al. 2010). Another study found reduced functional connectivity in ASD between the amygdala and FFA during face processing (though not FER), which was associated with social impairment (Kleinhans et al. 2008). All these findings suggest that dysfunction of the amygdala, and/or reduced amygdala-fusiform connectivity, plays an important role in an ASD-related FER deficit.

Yet the amygdala and FG are not the only brain regions where abnormalities are found in ASD during FER. While viewing emotional faces, fMRI and PET studies have shown that individuals with ASD also exhibit decreased activation in the cerebellum (Critchley et al. 2000), extrastriate cortices (Deeley et al. 2007), medial-frontal and orbito-frontal cortices (Loveland et al. 2008; Ogai et al. 2003), and inferior frontal gyrus (IFG) (Dapretto et al. 2006; Greimel et al. 2010; Hall et al. 2003; Ogai et al. 2003) compared to TD controls. In addition to reduced activation in selective regions, researchers have reported altered functional connectivity, as well as increased activation in certain regions in ASD when viewing emotional faces. Monk et al. (2010) found decreased functional connectivity between the medial temporal gyrus and right amygdala in ASD during the perception of emotional faces, along with some emotion-specific findings involving the right amygdala: increased connectivity with ventro-medial pre-frontal cortex when viewing happy faces, and decreased connectivity with the IFG when viewing sad faces. Furthermore, Wicker et al. (2008) reported abnormal effective connectivity, determined using dynamic causal modeling, between pre-frontal and posterior temporal regions in ASD during an FER task. Finally, in addition to Monk et al.'s (2010) finding of increased amygdala activity, increased activity in the STS and anterior cingulate cortex (ACC) (Ashwin et al. 2007; Hall et al. 2003; Pelphrey et al. 2007), occipital and anterior parietal regions (Dapretto et al. 2006), superior parietal lobule (Hubl et al. 2003), and precuneus (Wang et al. 2004) when viewing static facial emotions have been found in ASD. The authors of these studies suggest that activity in these regions was due to increased attention to specific features of faces and conscious monitoring of responses (Ashwin et al. 2007), increased visual and motor attention (Dapretto et al. 2006), a more local processing strategy (Hubl et al. 2003), and increased attentional load (Wang et al. 2004), which may be indicative of more effortful and less automatic processing of emotions than in TD controls. Overall, brain regions with reduced activation, regions with increased activation, and abnormal connectivity between regions during face processing in ASD suggest abnormality in the circuitry of the facial emotion processing system in these disorders; affective symptoms in ASD are likely the product of altered communication between brain regions rather than dysfunction of one region alone.

As in behavioral studies, the task format may influence results in fMRI studies. For example, some paradigms demand explicit processing of facial expressions (identifying the expression), whereas others require implicit processing (identifying another feature such as gender, or simply viewing expressive faces). In some cases, different results have been reported for explicit versus implicit FER tasks: Critchley et al. (2000) and Piggot et al. (2004) found diminished activation of the FFA in their ASD groups during explicit FER tasks, with normal amygdala activation (although, in Critchley et al.'s (2000) study, the ASD group was less accurate in the task, which might have affected fMRI findings). In contrast, during a gender discrimination task using the same faces, Critchley and colleagues (2000) found reduced amygdala and cerebellar activation compared to controls. These results, along with those of Monk and colleagues (2010), suggest that diminished amygdala activity can be overcome when the task format forces individuals with ASD to attend to the emotion expressed (Piggot et al. 2004). Even when considering only explicit tasks, the type of task used can affect results: Piggot et al. (2004) and Wang et al. (2004) found reduced FG activity in face-emotion matching tasks, but not in labeling tasks. Participants with ASD also had slightly poorer performance on the matching tasks, although Piggot and colleagues (2004) covaried behavioral performance from activation differences. In any case, their results suggest that the use of verbal labels might have an equalizing effect on brain activation (and behavioral performance) between individuals with ASD and TD individuals, again suggesting that verbal mediation might be a compensatory mechanism in some individuals with ASD.

In another type of task manipulation, some fMRI studies have examined responses to differing intensities of emotion in ASD. In one study, Deeley and colleagues (2007) found that individuals with Asperger's syndrome, unlike TD controls, did not modulate activity in fusiform and extrastriate cortices in response to differing intensities of disgust (although activity in these regions did vary by expression intensity for both groups when viewing happy and fearful faces). Ashwin and colleagues (2007) examined responses to neutral faces, scrambled faces, and both high and low intensity expressions of fear, and found that individuals with ASD, in contrast to controls, did not modulate the FFA, medial pre-frontal cortex, amygdala, or STS in response to the different conditions. Both of these studies used implicit processing tasks. Given these findings, combined with a report of diminished perceptual sensitivity in ASD (Bal et al. 2010), using explicit processing paradigms that vary the intensity of emotion in neuroimaging studies would be a productive direction for future research. These future studies will help to determine whether different brain regions are involved in identifying subtle versus fully expressed emotions in ASD.

Electrophysiological Studies

Another way to examine neural processes is through measuring electrophysiology, such as event-related potentials (ERP), which provide better temporal resolution of neural activity than fMRI, but at the expense of spatial resolution. Importantly, this method can measure only cortical activity, and not subcortical activity such as that of the amygdala. Nevertheless, three ERP studies have found ASD-related abnormalities in the context of FER. Dawson and colleagues (2004) reported that, in contrast to TD children, the N300 face-processing component in young children with ASD was not faster in the presence of fearful versus neutral faces. O'Connor et al. (2005), in a study of both children and adults with Asperger's syndrome, found delayed face-processing components during emotion identification compared to age-matched controls in adults only, along with poorer performance in adults, but not children. Wong and colleagues (2008), in contrast to the other studies, report normal surface ERP in children with high-functioning autism, but in dipole source analysis, found weaker and slower responses originating in frontal, fusiform, and visual cortices, along with slower and larger responses in parietal somatosensory cortices. The latter finding may again relate to more effortful processing of facial emotions in autism (Wong et al. 2008). Surprisingly, no studies have used magnetoencephalography (MEG) to investigate FER in ASD, although one study did examine the processing of neutral faces through this method (Bailey et al. 2005). The use of MEG in facial emotion research could help to clarify ERP findings, since source estimation in MEG shows better spatial resolution (Babiloni et al. 2009).

Autonomic Correlates of FER

Another type of measurement involves measuring autonomic arousal. Only two FER studies, to our knowledge, have used physiological measures of arousal. Hubert et al. (2009), measuring skin conductance responses, found reduced responses to emotional faces in an adult ASD group, indicating a lack of autonomic arousal in this condition. In addition, Bal and colleagues (2010), measuring respiratory sinus arrhythmia and heart rate, found evidence of higher *baseline* levels of arousal in ASD children. Possibly, individuals with ASD have both higher baseline levels of arousal and more trouble modulating this arousal than neurotypical individuals, which may play a role in their social-emotional deficits. For example, a high level of baseline arousal could reflect social anxiety, which might cause individuals with ASD to look at faces less in order to avoid this anxiety. However, further research must be carried out to investigate this issue.

Eye-tracking and brain-based studies, in addition to being more sensitive to subtle differences in emotion processing than purely behavioral studies, appear to be promising ways to investigate the underlying mechanisms through which individuals with ASD decode emotional facial expressions, and how these mechanisms might differ from those used by neurotypical individuals. The evidence so far suggests that individuals with ASD rely more on cognitive-perceptual systems than TD individuals, and less on social brain regions (see Fig. 1). These cognitive or perceptual mechanisms could include language, local processing, or other cognitive strategies, and probably vary between individuals. Indeed, Pierce et al. (2001), has found great variability in the neural circuitry used for neutral face processing among individuals with ASD (but not TD individuals).

However, it is important to note that eye-tracking and brain-based studies so far have involved relatively high-functioning individuals, and their findings therefore cannot be generalized to the entire autism spectrum. Although measuring eye movements and brain activity in low-functioning individuals is more difficult than measuring behavior, studies that do so will greatly improve our understanding of emotion processing in ASD. Furthermore, some of the fMRI studies that used explicit emotion-processing tasks found group differences in behavioral performance (Critchley et al. 2000; Hall et al. 2003; Piggot et al. 2004), which makes imaging findings difficult to interpret. Therefore, efforts should be made to match participants for behavioral performance in future imaging studies. Research on FER in ASD will also benefit from the rapidly expanding study of both functional and structural connectivity between brain regions, as the social deficits in these disorders are probably caused by dysfunctional communication between various regions of the brain.

Conclusions and Future Directions

The studies reviewed here provide evidence that individuals with ASD decode facial expressions differently than TD individuals. In some cases, they experience obvious difficulty labeling, or most often, matching emotions, and in other cases they perform as well as controls, perhaps through the use of compensatory mechanisms such as verbal mediation or feature-based learning. Demographic characteristics of participants, task demands, and the variables measured (e.g., behavior, BOLD response in fMRI, event-related potentials, or eye movements) all account for the heterogeneity of findings regarding FER in ASD. Overall, behavioral studies are only slightly more likely to find FER deficits in ASD than not; however, the fact that nearly all the eye-tracking, neuroimaging, and ERP studies have found group differences suggests that mixed findings in behavioral studies may be due to limits in the sensitivity of certain types of behavioral measures (e.g., faces depicting prototypical emotional expressions) to detect group differences. One outstanding question is whether abnormal FER is primary or secondary to the core social interaction deficit in ASD: does difficulty gleaning emotional information from faces lead to the broader social interaction deficit, or does reduced interest in social interaction contribute to a lack of specialization for faces and facial emotion processing? Questions for future research should include when and how this process becomes abnormal.

Before we understand how FER develops abnormally in ASD, however, we must understand how it develops in typical children. Evidence for improvement in FER throughout childhood, and even adolescence in the case of anger (Thomas et al. 2007), suggests that social experience plays a significant role in this process (Leppanen and Nelson 2006). The importance of social experience also provides a plausible explanation for abnormal FER in ASD; because infants with autism have demonstrated a lack of

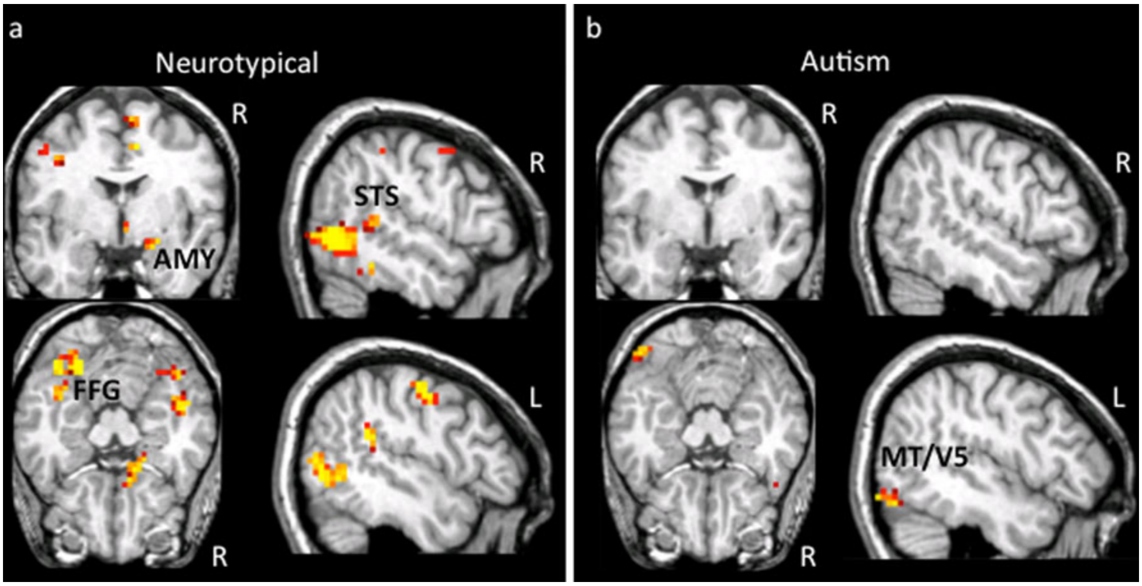

Fig. 1 From Pelphrey et al. (2007). *Social Cognitive and Affective Neuroscience, 2*(2), 140-149: Brain regions exhibiting greater activation to dynamic vs. static emotional faces in neurotypical adults and high-functioning adults with autism spectrum disorders. AMY amygdala, STS superior temporal sulcus, *FFG* fusiform gyrus

social orientation (Dawson et al. 1998), difficulty with establishing joint attention (Mundy et al. 1994), and a lack of orientation to faces (Clifford et al. 2007), they might have less social experience, and specific to this topic, less exposure to various facial expressions, leading to difficulty with FER (Grelotti et al. 2002). Abnormalities and deficits in FER that develop early in ASD could then further hinder social interaction, even if social orientation increases during later childhood and adolescence.

Brain imaging studies, when carried out with careful controls and analyses, can help to clarify whether and how individuals with ASD use compensatory mechanisms to recognize facial emotions. These individuals have been shown to activate the ACC (Ashwin et al. 2007) and precuneus (Wang et al. 2004) more than controls, while activating the amygdala and FG less (e.g., Ashwin et al. 2007; Wang et al. 2004). Because the ACC and precuneus are thought to be involved in self-monitoring and attentional load, these results again suggest that individuals with ASD decode facial expressions through more effortful, cognitively-based mechanisms than neurotypical individuals. Recently, a parallel finding was reported in the theory of mind (ToM) literature—while both neurotypical adults and two-year-old TD controls demonstrated implicit false-belief understanding as measured by eye movements, adults with Asperger's syndrome did not—however, adults with Asperger's syndrome were able to pass explicit ToM tasks with ease (Senju et al. 2009). Perhaps some individuals with ASD overcome automatic ToM and FER limitations in similar ways, through explicit cognitive mechanisms including, though not limited to, verbal mediation.

To examine the development of FER in ASD, both behavioral and brain-based longitudinal studies are also needed. Several cross-sectional behavioral studies investigating age-related changes in FER performance have been completed, and these tend to show a relative lack of improvement in ASD over time (O'Connor et al. 2005; Rump et al. 2009). These findings should be replicated longitudinally. In terms of neuroimaging, researchers are increasingly finding ways to scan young children and even infants (e.g., Dehaene-Lambertz et al. 2006), so the possibility for longitudinal studies beginning early in life is growing. This is important, because dysfunction in some brain structures, such as the amygdala, may be more pronounced earlier in life than later (Schultz 2005; Schumann et al. 2009). Given the strong involvement of the amygdala in FER, at least in typical development, it would be interesting to see if FER is associated with amygdala volume or activation in children with ASD. Two fMRI studies have found abnormal neural (including amygdala) responses to facial expressions in 12-year-old children (Dapretto et al. 2006; Wang et al. 2004), and ERP studies have reported aberrant neural activity in children with ASD as young as 3-4 years (Dawson et al. 2004). Children of these ages would be young enough to be tested again in later childhood, adolescence or even adulthood.

When we better understand how children with ASD decode emotional expressions, we will be able to develop more effective intervention programs that capitalize on their skills to facilitate their abilities to interact with others. Given results that suggest more cognitive and less automatic processing of faces in ASD, training paradigms that make the implicit more explicit in social situations might improve these individuals' social skills. In fact, a widely used intervention approach, Applied Behavioral Analysis, does this, breaking down appropriate social (and non-social) behaviors into small steps that are taught explicitly (Granpeesheh et al. 2009). Other recent approaches utilize computer-based programs for cognitive instruction of FER using both static and dynamic stimuli (e.g., Golan and Baron-Cohen 2006; Golan et al. 2010). Neurophysiological limitations might make it impossible to fundamentally change the way individuals with ASD process facial emotions, but if they can be taught to use alternative strategies effectively in real social situations, their quality of life may improve.

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