DOI: 10.1093/brain/awh194 *Brain* (2004), **127,** 1706–1716

Are patients with social developmental disorders prosopagnosic? Perceptual heterogeneity in the Asperger and socio-emotional processing disorders

Jason J. S. Barton,[1,2,4] Mariya V. Cherkasova,[1] Rebecca Hefter,[1] Terry A. Cox,[5] Margaret O'Connor[1] and Dara S. Manoach[3]

Departments of [1]Neurology and [2]Ophthalmology, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, MA, [3]Department of Psychiatry, Massachusetts General Hospital, and Athinoula A. Martinos Center, Harvard Medical School, Boston, MA, [4]Department of Bioengineering, Boston University, Boston, MA and [5]National Eye Institute, National Institutes of Health, Bethesda, MD, USA

Correspondence to: Jason J. S. Barton, Department of Neurology, KS 452, Beth Israel Deaconess Medical Center, 330 Brookline Avenue, Boston MA 02215, USA
E-mail: jbarton@bidmc.harvard.edu

Summary

It has been hypothesized that social developmental disorders (SDD) like autism, Asperger's disorder and the social-emotional processing disorder may be associated with prosopagnosic-like deficits in face recognition. We studied the ability to recognize famous faces in 24 adults with a variety of SDD diagnoses. We also measured their ability to discriminate changes in internal facial configuration, a perceptual function that is important in face recognition, and their imagery for famous faces, an index of their facial memory stores. We contrasted their performance with both healthy subjects and prosopagnosic patients. We also performed a cluster analysis of the SDD patients. One group of eight SDD subjects performed normally on all tests of face perception and recognition. The other 16 subjects were impaired in recognition, though most were better than prosopagnosic patients. One impaired SDD subgroup had poor perception of facial structure but relatively preserved imagery, resembling prosopagnosic patients with medial occipitotemporal lesions. Another subgroup had better perception than imagery, resembling one prosopagnosic with bilateral anterior temporal lesions. Overall, SDD subgroup membership by face recognition did not correlate with a particular SDD diagnosis or subjective ratings of social impairment.We conclude that the social disturbance in SDD does not invariably lead to impaired face recognition. Abnormal face recognition in some SDD subjects is related to impaired perception of facial structure in a manner suggestive of occipitotemporal dysfunction. Heterogeneity in the perceptual processing of faces may imply pathogenetic heterogeneity, with important implications for genetic and rehabilitative studies of SDD.

Keywords: Asperger's disorder; autism; face recognition; prosopagnosia

Abbreviations: DSM-IV = Diagnostic and Statistical Manual of Mental Disorders, 4th edition; IQ = intelligence quotient; SDD = social developmental disorder; SEPD = social-emotional processing disorder

Received January 9, 2004. Revised March 12, 2004. Accepted March 16, 2004. Advanced Access publication June 23, 2004

Introduction

Subjects with social developmental disorders (SDD) have a lifelong dysfunction in their interactions with other people. These conditions include autism, Asperger's disorder and the social-emotional processing disorder (SEPD), sometimes referred to as right hemisphere learning disability. The pathophysiology of these conditions remains unknown, and the aetiology of the majority of cases is unclear.

The human face is an important vehicle for social interaction. It communicates social engagement by the direction of gaze, emotional state by expression and social context by identification of its owner. The importance of the human face in social function is reflected in the fact that the diagnostic criteria for Asperger's disorder and SEPD include impaired eye-to-eye gaze and facial expression. Also, in addition to the failure of

these subjects to produce these social behaviours, it has been hypothesized that they fail to perceive these social cues in the faces of others. Thus, impaired perception of facial expression in SDD has been reported by some (Hobson, 1987; Gioia and Brosgole, 1988; Hobson *et al*., 1988; Tantam *et al*., 1989), but not others (Teunisse and De Gelder, 1994). Functional imaging studies have suggested that adults with autism or Asperger's disorder may fail to activate the fusiform face area during expression judgements (Critchley *et al*., 2000; Pierce *et al*., 2001).

Whether subjects with SDD are also impaired in recognizing facial identity is less certain. A possible link between developmental prosopagnosia—the failure to recognize familiar faces—and SDD has been suggested by reports that patients with childhood-onset prosopagnosia have SDD-like features (McConachie, 1976; Kracke, 1994; Barton *et al*., 2003; Pietz *et al*., 2003). Failure to recognize identity may impede the use of prior social encounters to cue role-appropriate interactions. The argument that perceptual deficits may lead to social failure is also supported by studies that report autistic-like features in some young children with visual loss (Fraiberg, 1977; Andersen *et al*., 1984; Goodman and Ashby, 1990; Cass *et al*., 1994; McAlpine and Moore, 1995; Brown *et al*., 1997) or apperceptive visual agnosia (Mottron *et al*., 1997; Jambaque *et al*., 1998).

However, a purported causal link between SDD and early-onset prosopagnosia can also run in the reverse direction (Trepagnier, 1998; Elgar and Campbell, 2001*a*, *b*; Grelotti *et al*., 2002). The expertise to discriminate the subtle differences that make a face unique likely develops during childhood, and requires both exposure and motivated interest (Carey, 1992). If there is a failure to develop normal social interest in others, even to the point of avoiding looking at faces (Swettenham *et al*., 1998), a normal perceptual expertise with faces may not evolve.

The implications of these two hypotheses differ. If poor social development impedes face recognition, then one might predict that all patients with SDD would be prosopagnosic. On the other hand, if childhood prosopagnosia impedes social development, then all prosopagnosic patients would have SDD, but it would not necessarily follow that all SDD patients would be prosopagnosic. That is, in this second scenario SDD could be a heterogeneous syndrome, with impaired face perception being only one of several factors that could lead to poor social skills.

The data on recognition of familiar faces in SDD is sparse and contradictory. While one study reported no deficit (Teunisse and De Gelder, 1994), another found impaired recognition of both faces and voices (Boucher *et al*., 1998). In this study, our first goal was to clarify the existance, degree and universality of impairments in face recognition in a group of adult subjects with SDD, mainly Asperger's disorder and/or SEPD.

Our second goal was to probe the origins of face recognition problems in these subjects. Face recognition is a complex process that can be conceptualized as a series of stages (Bruce and Young, 1986). Failures in this process can theoretically occur at a number of loci. These have been broadly divided into apperceptive forms, in which the encoding of facial structure is faulty, and associative forms, in which an accurate percept fails to be matched correctly to the appropriate facial memory, because of either disconnection or destruction of facial memory stores (Barton, 2003). Our work with acquired prosopagnosia has shown that some patients fail to perceive the configuration of internal facial structure (Barton *et al*., 2002) and thus fall into an apperceptive category, whereas others have a more associative type of deficit, with a severe loss of facial memories as accessed through imagery tests (Barton and Cherkasova, 2003). We applied the same tests to patients with SDD to determine whether perceptual or memory deficits for faces were present.

Our third goal was to contrast the findings in SDD subjects with those of prosopagnosic patients. The functional deficits we described in prosopagnosia had visible anatomic correlates. Those impaired in perception of facial structure had occipito-temporal lesions, particularly involving the region of the fusiform face area on the right, whereas more anterior temporal damage was associated with severe defects in facial imagery and relatively preserved perception (Barton *et al*., 2002; Barton and Cherkasova, 2003). If SDD subjects had patterns of results that resembled those of a particular subgroup of prosopagnosic patients, this may suggest a potential anatomic correlate for further investigation in SDD.

Patients and methods

Subjects

The study was approved by the Committee on Clinical Investigations at Beth Israel Deaconess Medical Center. All subjects gave written informed consent after the experimental procedures had been fully explained, according to the Declaration of Helsinki.

SDD

We tested 24 adults with SDD who were recruited from adult outpatient clinics offering neuropsychological assessment in the Boston area. We limited our sample to those aged 16 years and over, because there is some evidence that face recognition skills may continue to mature during childhood. Subjects were excluded for histories of acquired brain disease or significant brain injury after the age of 5 years. All but eight subjects were taking medications for mood disorders or attention deficit, including bupropion, fluoxetine, venlaxafine, methylphenidate, sertraline and eitalopram. Our sample consisted of seven women and 17 men, with a mean age of 35.1 years (SD 10.2, range 16–48 years).

Diagnoses were made by the referring neuropsychologist and were confirmed by a second licensed neuropsychologist (D.S.M.) based on a thorough review of psychological, neuropsychological and medical evaluations, and supplemented by an interview with the subject and a parental informant whenever possible. We obtained detailed histories with attention to birth-related events, developmental milestones,

emotional adjustment, social history and family history. In addition, behavioural observations from the neuropsychological evaluation (see below) and the interview were recorded. Special attention was given to observations regarding paralinguistic communication ability including the use of eye contact, facial expression and gesture. The supplemental interview and behavioural observations addressed the material covered by the Autism Diagnostic Interview—Revised (Short Edition) (Lord *et al*., 1994) in a format appropriate for adults, adolescents and their parental informants.

Various diagnostic labels have been applied to developmental conditions that affect the processing of social and emotional information. These include Asperger's disorder, autism, right hemisphere learning disability, non-verbal learning disability and SEPD. This reflects a lack of consensus about diagnostic criteria and the different approaches used to evaluate the subjects (psychiatric, neuropsychological, behavioural). Nevertheless, these different criteria overlap considerably in the area of social dysfunction. This is probably best captured by criteria A in the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (DSM-IV) diagnosis of Asperger's disorder: namely, 'qualitative evidence of impaired social interaction, manifest in non-verbal social behaviours, peer relationships, spontaneous social engagement, and social/emotional reciprocity'. We considered this, along with the exclusion of other pervasive developmental disorders and schizophrenia, to be the core criterion for the presence of an SDD.

Regarding specific diagnoses, our approach was planned to be neutral regarding the debate about diagnostic validity for separate SDD categories. We aimed to obtain sufficient information to determine whether subjects met criteria for each of three diagnostic categories: Asperger's disorder, high-functioning autism and SEPD. We considered subjects to have SDD if they met Asperger criterion A and also additional criteria for at least one of these three syndromes.

Diagnosis of Asperger's disorder by DSM-IV standards requires two additional criteria. First, subjects needed to demonstrate 'restricted repetitive and stereotyped patterns of behaviour, interests, and activities' (criterion B). This was considered present if subjects met the cut-off for autism on the repetitive behaviours and stereotyped patterns domain of the Autism Diagnostic Interview—Revised. Secondly, they had to have normal language development, specifically 'single words used by age 2 years and communicative phrases used by age 3 years' (criterion D).

In contrast, 'the lack of delay or deviance in early language development' is precisely what distinguishes Asperger's disorder from autism in DSM-IV. Therefore, failure to meet criterion D for Asperger, or a history suggestive of a loss or regression in language or communicative abilities, indicated a diagnosis of autism. Since our adult subjects were living independently and scored full-scale intelligence quotients (IQs) in the normal range, they are considered as high-functioning autism.

SEPD is also referred to as right-hemisphere learning disability (Denckla, 1983; Weintraub and Mesulam, 1983; Voeller, 1986; Manoach *et al*., 1995) and shares diagnostic criteria with non-verbal learning disability (Rourke, 1987; Semrud-Clikeman and Hynd, 1990; Gross-Tsur *et al*., 1995). These disorders are not in DSM-IV as they have been defined mainly by the neurological rather than the psychiatric community. However, there are similarities with Asperger's disorder. In our study, diagnostic criteria for SEPD overlapped with Asperger criteria A: 'qualitative impairments in social interaction', and the exclusions specified in criteria D and F: 'no clinically significant general delay in language' and 'criteria not met for another specific pervasive developmental disorder or schizophrenia'. However, while a diagnosis of SEPD does not require the repetitive or stereotyped patterns of behaviour seen in Asperger's disorder, it does require a neuropsychological profile indicating right hemispheric dysfunction, which Asperger's disorder does not. Thus, an SEPD diagnosis also requires normal verbal intellect (verbal IQ $\geqslant$ 90) and superior verbal versus non-verbal intellect as defined as a verbal IQ greater than performance IQ by 10 points or more (a 10-point discrepancy is significant at the $P = 0.05$ level; Wechsler, 1997). These criteria for SEPD are consistent with those of our previous studies (Weintraub and Mesulam, 1983; Sandson *et al*., 1994; Manoach *et al*., 1995, 1997) and of other groups (Voeller, 1986; Rourke, 1987; Semrud-Clikeman and Hynd, 1990; Gross-Tsur *et al*., 1995).

A substantial number of our subjects fulfilled criteria for both Asperger's disorder and SEPD. Subjects were classified as meeting criteria for Asperger's syndrome only ($n = 2$), SEPD only ($n = 11$), both Asperger's disorder and SEPD ($n = 8$), or high-functioning autism ($n = 3$).

Other controls

As a contrast to the subjects with SDD, we provide data from a series of 12 adult patients with prosopagnosia. Nine had an adult-onset and three a childhood-onset form. All but two have been described in our prior reports (Barton *et al*., 2001*a*, 2002, 2003; Barton and Cherkasova, 2003). Of these two one is LH, a well-studied patient with trauma to predominantly right anterior temporal and occipitotemporal regions and a small degree of left occipital damage, and the other is CG, a patient with recent right occipitotemporal infarction.

Different groups of healthy controls had been obtained to provide normative data on each of the tests we applied, and these will be described for each test.

Test protocols

Baseline evaluation

We recorded years of education, parental socioeconomic status as assessed by the Hollingshead Index (Hollingshead, 1965), and handedness using the Edinburgh handedness battery (White and Ashton, 1976). All SDD subjects were evaluated with the Wechsler Adult Intelligence Scale III (Wechsler, 1981), giving verbal and performance IQ.

Subjects also completed the Social Skills Inventory, a self-report questionnaire concerning their social functioning. This includes 90 statements about emotional and social competency, on which subjects rate themselves on a 5-point scale. The ratings are summed to give a maximal score of 450. Lower scores indicate poorer social function.

We administered two standard neuropsychological tests that involve face processing. One was the Benton Face Recognition Test (Benton and van Allen, 1972). Items on this test use a novel target face placed above an array of different faces, from which the subject must find the face that matches the target face for identity. On some portions of the test the array and target differ in viewpoint and lighting. This tests the ability to form accurate percepts of faces. We also administered a standard perceptual discrimination test not involving faces, the Benton Line Orientation Test.

The second was the Warrington Recognition Memory Test (Warrington, 1984). This has two portions, one using words, the other using faces. Each portion shows a subject 50 items, following which each item is paired with a distractor, and the subject indicates which of the two items had been previously seen. This test measures short-term familiarity for visually presented stimuli.

Famous face recognition

We presented patients with a series of 20 famous and 20 unfamiliar faces in random order, and asked them first to identify which were familiar, and secondly to name them if possible. The famous faces were taken from the industries of entertainment or politics, spanning a large time period from the 1940s to the present. The test was presented on a series of paper sheets, with no time limitations. From their hit rates (famous faces identified as familiar) and false alarm rates (non-famous faces identified as familiar) we constructed measures of their discriminative ability (d'), using signal detection theory methods.

As an adjustment for a given subject's prior knowledge of famous faces, we presented subjects with a list of the names of faces that they had failed to identify as famous. If they indicated that they had never heard or seen a certain person, that item was removed from the calculation of their final score. As further controls for exposure to and semantic knowledge about famous individuals, we used two famous names tests. One was a paired-name test, in which one famous name was paired with an invented name matched for ethnic origin. The famous names were again chosen to sample knowledge across many decades. In the other test, subjects sorted the names of 41 politicians and actors by occupation.

Normal controls for this test were 15 subjects with a mean age of 29.5 years (SD 8.9, range 21–52 years).

Famous face imagery

This consisted of 37 questions. These 37 were culled from a larger series of questions using two inclusion criteria for the final battery: (i) that at least 70% of normal controls chose to respond to it; and (ii) that at least 80% of these normal responders gave the correct answer. Each question required subjects to compare the facial appearance of two celebrities. Eighteen were questions about features (i.e. mouth, nose, eyes, moustache, glasses, mole). Examples include: 'Who has a wider mouth: Sophia Loren or Ingrid Bergman?', and 'Who has the bigger moustache: Adolf Hilter or Josef Stalin?' Nineteen were questions about the overall facial shape or configuration (i.e. angular, pear-shaped, round, gaunt, pinched, drawn). Examples include: 'Who has the more angular face: George Washington or Abraham Lincoln?', and 'Who has a more pear-shaped face: John F. Kennedy or Richard Nixon?' The celebrities were chosen to span a wide range of eras, with a concentration of faces familiar before 1990. The questions were mixed in random order. Subjects were allowed to omit a question if they had never heard of one member of the pair or did not recall seeing their face.

The controls for the imagery tasks were 31 normal subjects, of mean age 32.3 years (SD 9.5, range 22–60 years). Normal subjects omitted a mean of 3.6 questions (SD 3.7). We constructed 95% prediction intervals from the control data to define the normal range. The featural and configural components of the test were equivalent in difficulty in controls, with mean accuracy for featural imagery being 0.93 (SD 0.04), and for configural imagery being 0.94 (SD 0.06).

Perception of internal facial configuration

This test was run with a G4 Powermac computer in standard dim room lighting. The stimuli were full-colour digitized frontal images of one male and one female face. Each facial image occupied a square of 250 $\times$ 250 pixels. Target faces were made by altering one of four parameters, using Adobe Photoshop 5.0 (Adobe, San Jose, CA, USA). Two changes were increases in feature brightness, one being the colour of both irises, the other being the colour of the mouth. Percentage increases in brightness were 9, 12 and 15%. Two changes were distortions of feature position (Fig. 1). One was a reduction in interocular distance, by 10, 12 or 16 pixels, and one was an elevation of mouth position, by 6, 8 or 10 pixels. There is evidence that these aspects of internal facial structure are perceived by a normal orientation-dependent expert face processing system (Leder and Bruce, 2000; Barton *et al*., 2001*b*), and fail to be processed by prosopagnosic patients with right medial occipitotemporal lesions (Barton *et al*., 2002; Joubert *et al*., 2003). Therefore, in this report we focus upon the perception of the changes in feature position.

A trial stimulus consisted of three faces seen simultaneously on the screen, arranged equidistant from each other with the lower two slightly offset vertically. The target face occurred with equal probability at any of the three face positions, the other two faces being the same unaltered face. The subject's task was to indicate which face was the different one, with chance performance being 33% correct. Subjects were given 2 s to view each trial.

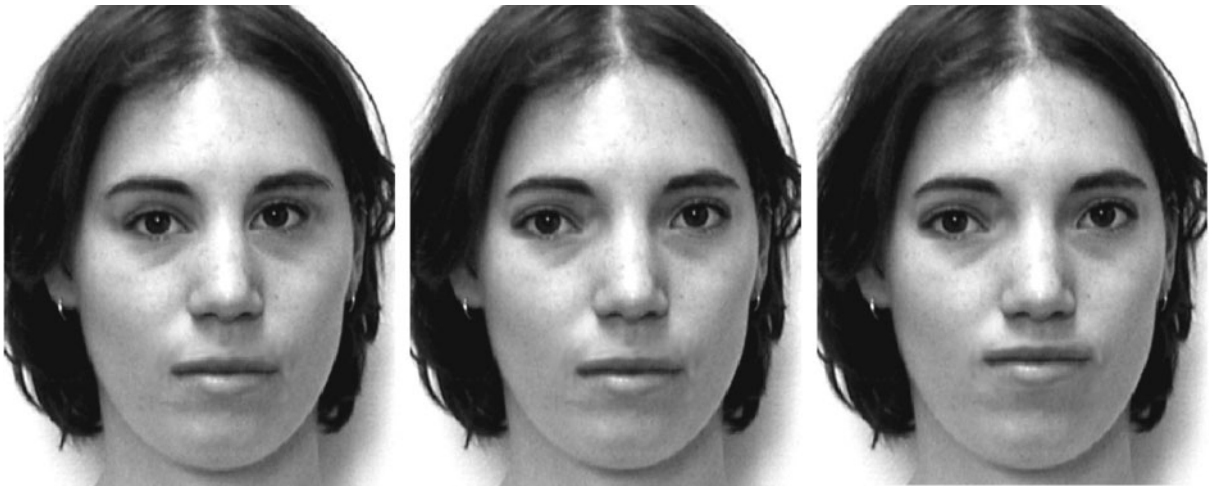

Fig. 1 Example of facial configurational changes used in perceptual testing. The middle face is the unaltered face. The left image has decreased inter-ocular distance, the right image has elevated mouth position.

We constructed testing blocks using the Superlab 1.71 program (Cedrus, Phoenix, AZ, USA). Each trial stimulus was presented nine times. With three levels of change for each of the four types of feature change, and two faces, there was a total of 216 trials. From the data we obtained an average accuracy score for the 108 trials with a target that had a change in feature position.

We tested 12 normal controls, aged 17–36 years. The mean and variance of their data were used to construct 95% prediction intervals for perception of facial configuration scores.

Analysis

Clusters among the SDD subjects were examined using data from the three different tests (famous face recognition, famous face imagery and perception of facial configuration). Spherically transformed data under a Euclidean metric were used in visualization and analysis; the transformed data were the scores on the three principal components scaled to unit variance. Data were analysed using R statistical software (www.r-project.org) with the add-on package 'cluster'. The GGobi data visualization system (www.ggobi.org) was used for visual formation of clusters. Additional cluster analyses were performed with both agglomerative and divisive hierarchical algorithms (Kaufman and Rousseeuw, 1990; Everitt *et al*., 2001). A Monte Carlo test of non-randomness of the transformed data was performed. We generated random uniform data within the cube defined by maximum likelihood estimates derived from the original sphered data. We then compared the distribution of Euclidean distances in the original and simulated data using the Kolmogorov–Smirnov test. We performed comparisons with 100 simulated datasets, and our test statistic was the number of P values <0.05. For the distribution of this statistic under the null hypothesis, we repeated the procedure 100 times using random datasets, each compared with 100 sets of simulated data.

Results

Face recognition

The key finding on famous face recognition was that eight SDD subjects had very accurate discrimination of face familiarity, with $d' > 2.9$ (Fig. 2, Table 1). This is well within the range of normal subjects, who produced d' ranging from 2.19 to 3.88, and shows that SDD does not always impede the development of a normal ability to recognize facial identity.

There was a clear separation between this normally performing group (SDD-1) and the other 16 SDD subjects, who had d' ranging from 0.75 to 2.25. The scores of this 'impaired group' (SDD-2) spanned a range from borderline low-normal to abnormal. However, these SDD-2 subjects were not as impaired on face recognition as our prosopagnosic patients, whose d' ranged from -0.61 to 1.12. Hence the face recognition defect in the impaired SDD-2 group is intermediate, lying in a zone between the normal subjects and the prosopagnosic patients.

Very few faces had to be discarded because the celebrities were unknown to the subjects of either group. The mean number of faces discarded was 0.89 for SDD-1 and 1.38 for the impaired SDD-2 group, an insignificant difference. Both groups also scored well on the name recognition control tests. On the paired-name test, SDD-1 subjects correctly identified the famous name on 98% of trials and SDD-2 subjects on 96% of trials. On sorting famous names by occupation, SDD-1 subjects were 100% accurate and SDD-2 subjects 98% accurate. These findings verify that the SDD subjects had sufficient knowledge of popular culture to perform our famous face recognition test.

Face imagery and perception of facial configuration

These data showed a wide spectrum of results for SDD subjects, from normal performance to impairments as severe as those seen in our prosopagnosic patients (Fig. 3). In relation to

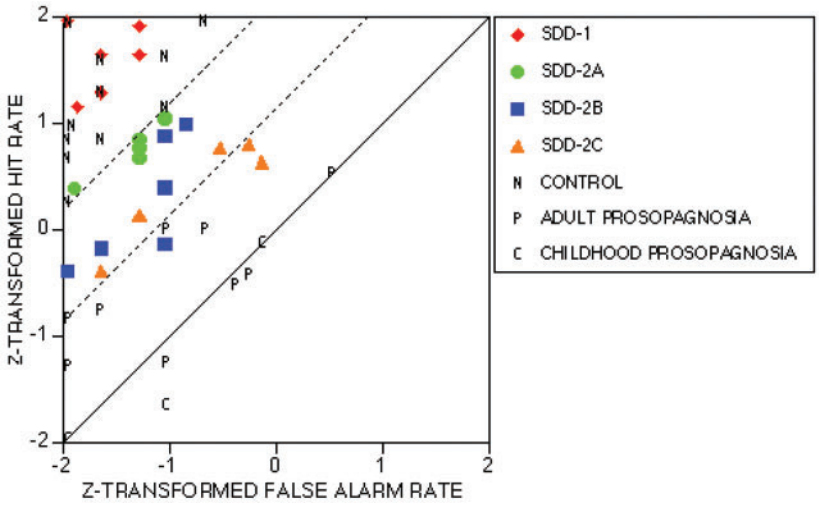

Fig. 2 Receiver–operator plot of famous face identification. The normalized Hit rate (number of famous faces identified as famous) is plotted against the normalized false-positive rate (number of anonymous faces identified as famous). Solid diagonal line denotes where hit rate equals false-positive rate, and there is no discriminative ability (d′ = 0). Solid symbols are those of SDD subjects, who are contrasted against prosopagnosic and normal subjects. The upper dashed line forms the lower border of the scores of normal subjects; the lower dashed line forms the upper border of the prosopagnosic subjects. Note the normal performance of SDD-1 subjects, and the impaired performance of SDD-2 subjects, who in general are in a zone intermediate between normal and prosopagnosic performance. SDD-2 subgroups are also shown, as per the cluster analysis (see text for details).

Table 1 *Performance of the SDD subgroups and controls on the three face tests*

		Face recognition (d′)		Face imagery (accuracy score)		Face perception (accuracy score)	
	n	Mean	SD	Mean	SD	Mean	SD
Normal controls		2.77	0.42	0.93	0.04	0.86	0.12
Prosopagnosic (occipitotemporal)		0.37	0.57	0.81	0.06	0.44	0.07
SDD subjects							
Normal							
SDD-1	8	3.31	0.40	0.88	0.07	0.84	0.09
Impaired							
SDD-2A	5	2.09	0.11	0.89	0.02	0.55	0.12
SDD-2B	6	1.52	0.36	0.69	0.06	0.51	0.13
SDD-2C	5	1.16	0.25	0.79	0.07	0.71	0.06

their performance on face recognition, the group with normal recognition did better on both imagery and perception than subjects with poor face recognition, though there was more overlap on the imagery data than on the results for perception of configuration. Thus the data show that ability on these three functions is related.

Our previous study of prosopagnosic patients showed that right occipitotemporal lesions were associated with impaired imagery for general facial configuration, whereas bilateral occipitotemporal lesions were associated with impaired imagery for both configuration and features (Barton and Cherkasova, 2003). The data on these subtests of imagery in our SDD groups did not suggest any greater deficit for configuration over features in the SDD-2 group; however, in the SDD-1 group there was a slight difference of ~6% in favour of better imagery for facial features (paired *t*-test, $P < 0.058$) (Fig. 4).

Cluster analysis of subgroups of SDD

The Monte Carlo test of non-randomness of the data yielded an expected *P* value of 0.03, indicating that clustering was present in the data. This analysis yielded several clusters. One cluster of eight subjects (SDD-1) performed well on recognition, imagery and perception (Fig. 3), with their data located in a zone of normal performance on all three tests. Further segmentation suggested that the impaired cluster of 16 subjects (SDD-2) could be divided into two and possibly three impaired subgroups (Table 1). One subgroup of five subjects (SDD-2A) performed better on imagery and face recognition and worse on configurational perception. Another group of five (SDD-2C) performed better on perception of configuration and poorer on imagery. The third group, SDD-2B, was not as clearly differentiated from SDD-2A. While both SDD-2A and -2B subgroups were similarly impaired on perceptual testing, the SDD-2B group fared worse on imagery. Whether this

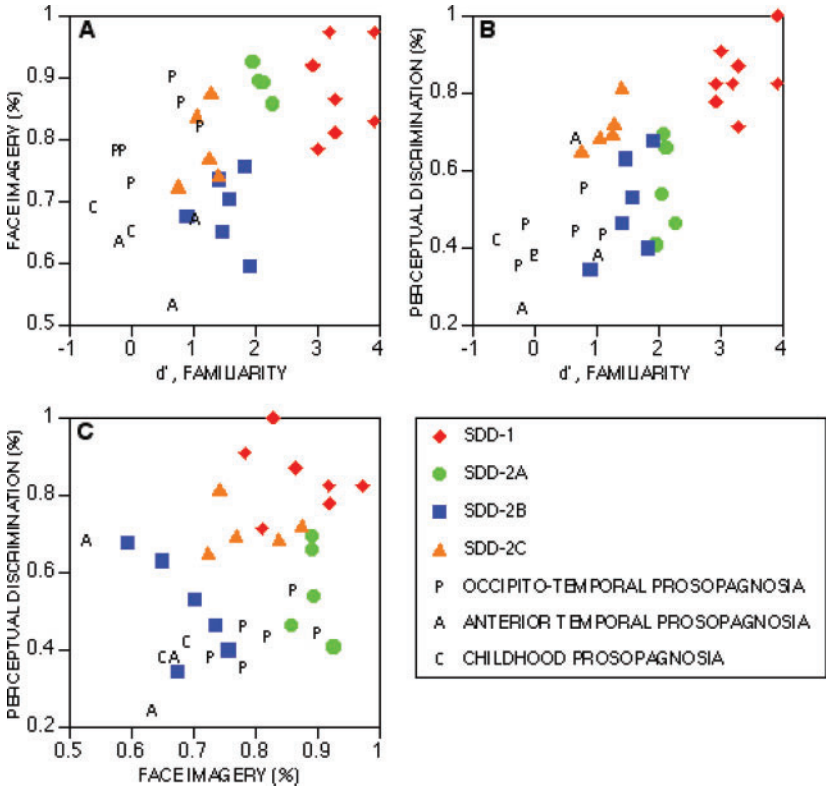

Fig. 3 Relation of face imagery, face perceptual discrimination and famous face recognition (d′ familiarity). Consider these three measures as the axes of a 3D space. The graphs are projections of the data onto the three planar faces of this space. Symbols as in Fig. 2, with SDD subgroups defined by cluster analysis. Note that SDD-1 subjects perform well on all tests. While both SDD-2A and SDD-2B are impaired on perceptual discrimination, SDD-2B subjects are more impaired on imagery and famous face recognition. The SDD-2C group does well on perceptual discrimination, but is not as good as the SDD-2A group on imagery.

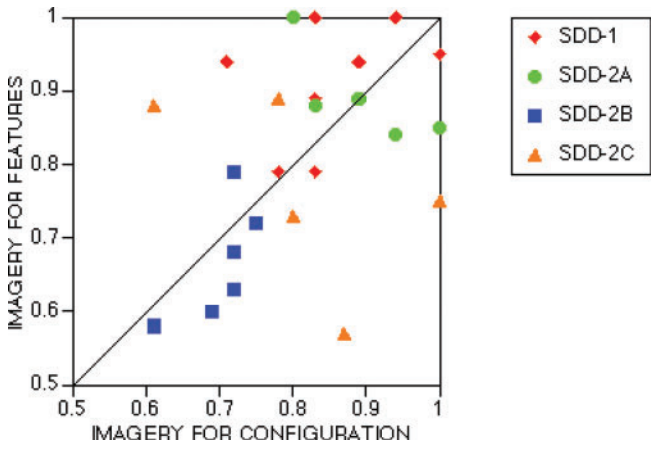

Fig. 4 Feature versus configuration imagery. There is no selective deficit for SDD overall, but the SDD-1 group is slightly better on feature than configuration imagery.

represents a distinct cluster or a spectrum of imagery performance within a single group is not clear.

It is of interest to compare the impaired SDD subjects with prosopagnosic patients on the same tests. As mentioned, face recognition was worse in prosopagnosics than SDD subjects. However, performance on imagery and perception showed more overlap between prosopagnosia and the impaired SDD-2 group. The pattern of more selective impairment of perception compared with imagery in SDD-2A is reminiscent of the performance of prosopagnosic patients with lesions of the fusiform face area. This is shown in Table 1 and in the plot of face imagery versus face perception, where SDD-2A subjects had results that overlapped those of prosopagnosic patients with occipitotemporal lesions (Fig. 3C). Patients in the SDD-2C subgroup had low-normal perceptual scores but worse imagery scores. In this sense they resembled the prosopagnosic patient with bilateral anterior temporal lesions, who had normal perceptual abilities but no residual facial imagery. While the SDD-2C group had better imagery capabilities than her, their pattern of results may be suggestive of partial, more anterior temporal dysfunction.

Characteristics of SDD subgroups

We wished to determine whether the groups with normal (SDD-1) and abnormal (SDD-2) face recognition differed on other characteristics (Table 2). There was no significant difference in age, years of education or parental socioeconomic status. Their performance on neuropsychological testing of

Table 2 *Characteristics of the different SDD subgroups*

	Normal recognition SDD-1		Impaired recognition SDD-2			Impaired recognition subgroups					
						SDD-2A		SDD-2B		SDD-2C	
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD
General data											
Number of subjects	8		16			5		6		5	
Gender (number females)	2		5			2		2		1	
Age (years)	39.6	5.1	32.8	11.5		39.4	11.9	29.2	9.5	30.6	12.7
Education (years)	16.1	1.8	14.9	3.3		15.4	2.9	13.7	2.7	16.0	4.3
Parental socioeconomic	2.1	1.4	1.7	1.0		1.6	0.5	1.7	1.2	1.8	1.5
IQ, verbal	120	18	115	20		119	11	106	24	122	21
IQ, performance	107	23	90	17	$P = 0.057$	95	8	77	19	102	12
IQ, full scale	113	21	108	12		109	11	102	8	115	15
Diagnostic category											
Asperger only	2		1			0		1		0	
Asperger and SEPD	3		5			0		2		3	
SEPD only	2		8			5		2		1	
High-functioning autism	1		2			0		1		1	
Social Skills Inventory	235	26.5	243	40.2		213	11.6	263	53.8	248	24
Neuropsychological results											
Warrington Words (x/50)	49.5	1.1	48.7	2.2		48.2	1.6	49.5	0.8	48.2	3.5
Benton Line Orientation (x/30)	27.1	3.6	24.4	5.3		25.2	3.6	22.8	7.5	25.4	4.2
Warrington Faces (x/50)	45.0	5.1	38.1	5.0	$P < 0.004$	40.0	4.9	35.5	5.2	39.4	4.2
Benton Faces (x/54)	49.0	3.8	43.3	4.7	$P < 0.007$	45.6	3.7	41.5	5.7	43.0	4.2

P values indicate significant differences between the normal SDD-1 and the impaired SDD-2 subgroups.

face processing mirrored the results of the above tests. The normal SDD-1 group performed better on the Benton Face Recognition Test and the Warrington Recognition Memory Subtest for Faces than the abnormal SDD-2 group, though the groups performed equally well on the Warrington Subtest for Words and the Benton Line Orientation Test. While their verbal IQs were also similar, there was a trend to worse performance IQ in the group with impaired face recognition.

What about diagnostic criteria? The frequency of diagnoses of Asperger's disorder and SEPD among the groups was similar for SDD-1 (normal recognition) and SDD-2. χ^2-tests of the distribution of each of these diagnoses across the two main SDD groups were not significant [$\chi^2(1) = 0.34$, $P = 0.56$ for Asperger; $\chi^2(1) = 0.72$, $P = 0.72$ for SEPD]. Thus, having a diagnosis of Asperger or SEPD did not predict whether a subject was more likely to have normal or impaired processing of facial identity. Although there were too few autism patients for statistical evaluation, one of these three patients had normal face processing and two were impaired.

We also examined the degree of self-perceived social dysfunction on the Social Skills Inventory. Published data show a normal range of 250–314. The mean scores for all our subgroups fell below this range, indicating that our subjects were aware of their social difficulties. However, there was no difference in the scores of the SDD-1 and SDD-2 groups: in fact, the SDD-1 mean score was slightly lower than that of the impaired SDD-2 group (Table 2).

Table 2 also shows data for the SDD-2 subgroups, but we considered the numbers in these subdivisions too small for statistical analysis.

Discussion

The chief finding of this study was that a distinct subgroup of SDD subjects had normal famous face recognition, which was also accompanied by normal perception of facial configuration, normal imagery for famous faces and good performance on standard neuropsychological tests of face perception and memory. Thus, on a variety of tests that probed different aspects of face processing relevant to the extraction of identity, these subjects repeatedly performed well, with scores comparable to normal subjects. The inescapable conclusion is that processing of facial identity is normal in this SDD-1 subgroup. Therefore, the presence of SDD does not inevitably lead to impaired face recognition.

On the other hand, the second important finding was that a substantial proportion (66%) of SDD subjects were impaired on face recognition. Significantly, baseline characteristics or the specific SDD diagnosis based upon current clinical criteria (Asperger's disorder, high-functioning autism or SEPD) did not differ between those with impaired versus those with normal face recognition skills. Therefore, face perception deficits could not be predicted from prior diagnostic information.

The face recognition and face perception deficits in the impaired SDD-2 group were generally not as profound as those in the prosopagnosic patients, however. Only a few subjects had d′ values in the upper range of prosopagnosic subjects. These few individuals might be considered equivalent to the rare case reports of prosopagnosia with SDD in the literature (Kracke, 1994; Pietz *et al*., 2003); otherwise, most SDD-2 subjects had an intermediate face recognition defect, lying between the normal subjects and the prosopagnosic patients.

How do our data compare with previous reports? Compared with the work on facial expression, there are few studies on face perception and recognition in SDD, most of which have studied autism rather than Asperger's disorder or SEPD. While there is general agreement that autistic children do recognize the object category of faces (Volkmar *et al*., 1989; Teunisse and De Gelder, 1994), i.e. at an elementary categorical level, the data on the more difficult subordinate ('within-category') process of perceiving and recognizing the identity of specific faces have been mixed in these disorders.

One 'within-category' task is matching simultaneously viewed novel faces, as assessed by instruments like the Benton Face Recognition Test. Studies have reported deficits in matching faces for autistic children (Tantam *et al*., 1989), as well as children with high-functioning autism or Asperger's disorder (Szatmari *et al*., 1990; Davies *et al*., 1994). However, one study of autistic children did not find this for either full or partially obscured faces, in contrast to deficits for matching facial emotions (Hobson *et al*., 1988). Our perceptual test for facial configuration is a more controlled variant of face matching, as it requires subjects to determine which two of three faces are identical, the third differing in a very specific manner. The results show that face perception deficits do exist in a subset of SDD subjects, and that these disturbances persist into adult life. Therefore, this group has a persistent disability, and not just delayed maturation of facial perceptual skills.

A related task to perceptual matching is delayed recognition. This requires subjects to recognize recently encountered faces that are presented again after a variable interval. The Warrington Recognition Memory Test is an example. One study found normal performance in autistic children, in contrast to impaired recognition of expression (Celani *et al*., 1999). However, other studies have found deficits in delayed recognition of faces in childhood autism (Boucher and Lewis, 1992; Klin *et al*., 1999).

Although matching and delayed recognition likely measure abilities relevant to identity recognition, they are not defining criteria for prosopagnosia. Rather, the core defect of this disorder is the inability to recognize known faces. Very few studies have examined this function. Some have shown intact recognition of upright faces in autistic children (Langdell, 1978; Teunisse and De Gelder, 1994), although the mechanism of recognition may have differed from normal subjects, as autistic children place less emphasis on the upper face (Langdell, 1978). One study of autistic children found impaired recognition of school staff. However, inspection of the data shows that a substantial number of autistic subjects performed in the same range as the controls (Boucher *et al*., 1998). Our results extend this work to adult patients with Asperger's disorder and SEPD, and also show a similar spectrum of ability, with some subjects performing normally and some impaired.

The identification of SDD subjects with normal face recognition poses a challenge for the hypothesis that the presence of social dysfunction impedes the development of normal face recognition. This hypothesis, in its most restrictive form, would predict that all SDD subjects would be impaired. Our data show that this is not the case. A more liberal form might state that face recognition deficits would exist, but be modulated by the severity of social dysfunction. Quantifying social dysfunction is a difficult task, particularly in adults. We used the Social Skills Inventory to attempt to capture this aspect. The results showed no difference between the normal SDD-1 group and the impaired SDD-2 group. While this instrument is limited in that it is a subjective rather than an objective index of social disability, the results agree with a prior study of children that found that social function does not correlate with the competency of face processing (Klin *et al*., 1999).

An alternative hypothesis is that face processing impairments are primary deficits in these patients and not caused by the social disorder. In addition to the fact that SDD does not preclude normal face recognition, the finding of distinct impaired SDD-2 subgroups would support this hypothesis. This finding suggests that there may be different types of face-processing failures within the SDD-2 group, much as acquired prosopagnosia is itself a family of dysfunctions, each affecting a different level in the face-processing hierarchy (Barton, 2003). Thus, the SDD-2A group's pattern of deficits on our tests of imagery and perception resembles a milder version of the defect in prosopagnosic patients with medial occipitotemporal lesions in the region of the fusiform face area (Barton *et al*., 2002). As such, this provides a behavioural parallel to reports that adults with Asperger's disorder or autism have impaired activation of the fusiform face area during face matching (Schultz *et al*., 2000) or judgements of expression or sex (Critchley *et al*., 2000; Pierce *et al*., 2001). In normal subjects, the fusiform face area is activated most during functional imaging by tasks involving recognizing facial identity (Haxby *et al*., 2000); hence, abnormalities in this region might be associated with face recognition impairments in SDD. On the other hand, patterns of impaired imagery with relatively spared perception of facial configuration would be more suggestive of a failure to access facial memories, an associative type of defect that resembles the results in a prosopagnosic patient with bilateral anterior temporal lesions (Barton and Cherkasova, 2003).

The possibility that impaired perceptual processing exists in SDD is supported by other data. One study found impaired perception of the configuration of non-facial abstract visual stimuli (Davies *et al*., 1994), and we are also currently examining the perception of spatial configuration in abstract dot patterns in our patients. Whether a perceptual deficit could play a causal role in social dysfunction, as others have hypothesized (Kracke, 1994), is less certain, however. It must also be considered that face processing impairments and SDD may be associated deficits with no causal relationship. That is, face perceptual deficits may be correlated with SDD through some shared anatomical or physiological susceptibility to a pathogenetic mechanism. For example, some hypothesize that damage to a mesolimbic system in the frontal and temporal lobes is at fault in autism (Damasio and Maurer, 1978), and indeed there are cases of autistic-like syndromes with temporal lobe lesions (DeLong *et al*., 1981; Gillberg, 1986, 1991;

Mottron *et al*., 1997). Since the temporal lobe is involved in high-level visual processing, visual dysfunction may be an additional result, but this could represent 'bystander' damage to neighbouring visual areas rather than a causal relationship. More rigorous study of the social function of developmental prosopagnosics would be helpful in this regard. If the face recognition defect in early-onset prosopagnosia is found to correlate with social dysfunction, this would be more plausible evidence for a causal link.

In conclusion, we find that SDD is compatible with normal face recognition skills. Among those in whom processing of facial identity is impaired, there is a subgroup with perceptual deficits that implicates dysfunction of medial occipitotemporal cortex. Further studies contrasting the functional and structural imaging of this region between normal and impaired subgroups of SDD would be useful in advancing our knowledge of this disorder. Perceptual and structural heterogeneity of face processing in SDD may imply a pathogenetic heterogeneity to SDD itself, which in turn would have important implications for genetic and rehabilitative studies of SDD. The status of face perception and recognition in this syndrome may prove to be an important marker in future work on the Asperger and SEPD syndromes.

Acknowledgements

J.J.S.B. was supported by NIMH grant 1R01 MH069898-01 and NINDS grant 1K08 NS01920-01A1.

References

Andersen E, Dunlea A, Kekelis L. Blind children's language: resolving some differences. J Child Lang 1984; 11: 645–64.

Barton J. Disorders of face perception and recognition. Neurol Clin 2003; 21: 521–48.

Barton J, Cherkasova M. Face imagery and its relation to perception and covert recognition in prosopagnosia. Neurology 2003; 61: 220–5.

Barton J, Cherkasova M, O'Connor M. Covert recognition in acquired and developmental prosopagnosia. Neurology 2001a; 57: 1161–7.

Barton J, Keenan J, Bass T. Discrimination of spatial relations and features in faces: effects of inversion and viewing duration. Br J Psychol 2001b; 92: 527–49.

Barton J, Press D, Keenan J, O'Connor M. Lesions of the fusiform face area impair perception of facial configuration in prosopagnosia. Neurology 2002; 58: 71–8.

Barton J, Cherkasova M, Press D, Intriligator J, O'Connor M. Developmental prosopagnosia: a study of three patients. Brain Cogn 2003; 51: 12–30.

Benton A, van Allen M. Prosopagnosia and facial discrimination. J Neurol Sci 1972; 15: 167–72.

Boucher J, Lewis V. Unfamiliar face recognition in relatively able autistic children. J Child Psychol Psychiatry 1992; 33: 843–59.

Boucher J, Lewis V, Collis G. Familiar face and voice matching and recognition in children with autism. J Child Psychol Psychiatry 1998; 39: 171–81.

Brown R, Hobson R, Lee A, Stevenson J. Are there autistic-like features in congenitally blind children? J Child Psychol Psychiatry 1997; 38: 693–703.

Bruce V, Young A. Understanding face recognition. Br J Psychol 1986; 77: 305–27.

Carey S. Becoming a face expert. Philos Trans R Soc Lond B Biol Sci 1992; 335: 95–103.

Cass H, Sonksen P, McConachie H. Developmental setback in severe visual impairment. Arch Dis Child 1994; 70: 192–6.

Celani G, Battacchi MW, Arcidiacono L. The understanding of the emotional meaning of facial expressions in people with autism. J Autism Dev Disord 1999; 29: 57–66.

Critchley HD, Daly EM, Bullmore ET, Williams SC, Van Amelsvoort T, Robertson DM, et al. The functional neuroanatomy of social behaviour: changes in cerebral blood flow when people with autistic disorder process facial expressions. Brain 2000; 123: 2203–12.

Damasio A, Maurer R. A neurological model for childhood autism. Arch Neurol 1978; 35: 777–86.

Davies S, Bishop D, Manstead A, Tantam D. Face perception in children with autism and Asperger's syndrome. J Child Psychol Psychiatry 1994; 35: 1033–57.

DeLong G, Bean S, Brown F. Acquired reversible autistic syndrome in acute encephalopathic illness in children. Arch Neurol 1981; 38: 191–4.

Denckla M. The neuropsychology of social-emotional learning disabilities. Arch Neurol 1983; 40: 461–2.

Elgar K, Campbell R. Annotation: the cognitive neuroscience of face recognition: implications for developmental disorders. J Child Psychol Psychiatry 2001a; 42: 705–17.

Elgar K, Campbell R. The development of face-identification skills: what lies behind the face module? Infant Child Dev 2001b; 10: 25–30.

Everitt B, Landau S, Leese M. Cluster analysis. 4th ed. London: Arnold; 2001.

Fraiberg S. Insights from the blind. London: Souvenir Press; 1977.

Gillberg I. Onset at age 14 of a typical autistic syndrome. A case report of a girl with herpes simplex encephalitis. J Autism Dev Disord 1986; 16: 369–75.

Gillberg I. Autistic syndrome with onset at age 31 years: herpes encephalitis as a possible model for childhood autism. Dev Med Child Neurol 1991; 33: 920–4.

Gioia JV, Brosgole L. Visual and auditory affect recognition in singly diagnosed mentally retarded patients, mentally retarded patients with autism and normal young children. Int J Neurosci 1988; 43: 149–63.

Goodman R, Ashby L. Delayed visual maturation and autism. Dev Med Child Neurol 1990; 32: 814–9.

Grelotti DJ, Gauthier I, Schultz RT. Social interest and the development of cortical face specialization: what autism teaches us about face processing. Dev Psychobiol 2002; 40: 213–25.

Gross-Tsur V, Shalev R, Manor O, Amir N. Developmental right-hemisphere syndrome: clinical spectrum of the nonverbal learning disability. J Learn Disabil 1995; 28: 80–6.

Haxby J, Hoffman E, Gobbini M. The distributed human neural system for face perception. Trends Cogn Sci 2000; 4: 223–33.

Hobson RP. The autistic child's recognition of age- and sex-related characteristics of people. J Autism Dev Disord 1987; 17: 63–79.

Hobson R, Ouston J, Lee A. What's in a face? The case of autism. Br J Psychol 1988; 79: 441–53.

Hollingshead A. Two factor index of social position. New Haven (CT): Yale University Press; 1965.

Jambaque I, Mottron L, Ponsot G, Chiron C. Autism and visual agnosia in a child with right occipital lobectomy. J Neurol Neurosurg Psychiatry 1998; 65: 555–60.

Joubert S, Felician O, Barbeau E, Sontheimer A, Barton J, Ceccaldi M, et al. Impaired configurational processing in a case of progressive prosopagnosia associated with predominant right temporal lobe atrophy. Brain 2003; 126: 2537–50.

Kaufman L, Rousseeuw P. Finding groups in data: an introduction to cluster analysis. New York: John Wiley; 1990.

Klin A, Sparrow SS, de Bildt A, Cicchetti DV, Cohen DJ, Volkmar FR. A normed study of face recognition in autism and related disorders. J Autism Dev Disord 1999; 29: 499–508.

Kracke I. Developmental prosopagnosia in Asperger syndrome: presentation and discussion of an individual case. Dev Med Child Neurol 1994; 36: 873–86.

Langdell T. Recognition of faces: an approach to the study of autism. J Child Psychol Psychiatry 1978; 19: 255–68.

Leder H, Bruce V. When inverted faces are recognized: the role of configural information in face recognition. Q J Exp Psychol 2000; 53A: 513–36.

Lord C, Rutter M, Le Couteur A. Autism Diagnostic Interview—Revised: a revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. J Autism Dev Disord 1994; 24: 659–85.

Manoach D, Sandson T, Weintraub S. The developmental social-emotional processing disorder is associated with right hemispheric abnormalities. Neuropsychiatry Neuropsychol Behav Neurol 1995; 8: 99–105.

Manoach D, Weintraub S, Daffner K, Scinto L. Deficient antisaccades in the social-emotional processing disorder. Neuroreport 1997; 8: 901–5.

McAlpine L, Moore C. The development of social understanding in children with visual impairments. J Visual Impairment Blindness 1995; 89: 349–58.

McConachie H. Developmental prosopagnosia. A single case report. Cortex 1976; 12: 76–82.

Mottron L, Mineau S, Décarie J-C, Jambaqué I, Labrecque R, Pépin J-P, et al. Visual agnosia with bilateral temporo-occipital brain lesions in a child with autistic disorder: a case study. Dev Med Child Neurol 1997; 39: 699–705.

Pierce K, Muller RA, Ambrose J, Allen G, Courchesne E. Face processing occurs outside the fusiform 'face area' in autism: evidence from functional MRI. Brain 2001; 124: 2059–73.

Pietz J, Ebinger F, Rating D. Prosopagnosia in a preschool child with Asperger syndrome. Dev Med Child Neurol 2003; 45: 55–7.

Rourke B. Syndrome of nonverbal learning disabilities: the final common pathway of white-matter disease/dysfunction? Clin Neuropsychol 1987; 1: 209–34.

Sandson T, Manoach D, Price B, Rentz D, Weintraub S. Right hemisphere learning disability associated with left hemisphere dysfunction: anomalous dominance and development. J Neurol Neurosurg Psychiatry 1994; 57: 1129–32.

Schultz RT, Gauthier I, Klin A, Fulbright RK, Anderson AW, Volkmar F, et al. Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and Asperger syndrome [see comments]. Arch Gen Psychiatry 2000; 57: 331–40.

Semrud-Clikeman M, Hynd G. Right hemispheric dysfunction in nonverbal learning disabilities: social, academic, and adaptive functioning in adults and children. Psychol Bull 1990; 107: 196–209.

Swettenham J, Baron-Cohen S, Charman T, Cox A, Baird G, Drew A, et al. The frequency and distribution of spontaneous attention shifts between social and nonsocial stimuli in autistic, typically developing, and non-autistic developmentally delayed infants. J Child Psychol Psychiatry 1998; 39: 747–53.

Szatmari P, Tuff L, Finlayson M, Bartolucci G. Asperger's syndrome and autism: neurocognitive aspects. J Am Acad Child Adolesc Psychiatry 1990; 29: 130–6.

Tantam D, Monaghan L, Nicholson H, Stirling J. Autistic children's ability to interpret faces: a research note. J Child Psychol Psychiatry 1989; 30: 623–30.

Teunisse J-P, De Gelder B. Do autistics have a generalized face processing deficit? Int J Neurosci 1994; 77: 1–10.

Trepagnier C. Autism etiology: a face-processing perspective. Brain Cogn 1998; 37: 158–60.

Voeller K. Right-hemisphere deficit syndrome in children. Am J Psychiatry 1986; 143: 1004–9.

Volkmar F, Sparrow S, Rende R, Cohen D. Facial perception in autism. J Child Psychol Psychiatry 1989; 30: 591–8.

Warrington E. Warrington Recognition Memory Test. Los Angeles: Western Psychological Services; 1984.

Wechsler D. Wechsler Adult Intelligence Scale—Revised. New York: Psychological Corporation; 1981.

Wechsler D. WAIS-III: Wechsler Adult Intelligence Scale. 3rd ed. San Antonio: Psychological Corporation; 1997.

Weintraub S, Mesulam M. Developmental learning disabilities of the right hemisphere. Emotional, interpersonal, and cognitive components. Arch Neurol 1983; 40: 463–8.

White K, Ashton R. Handedness assessment inventory. Neuropsychologia 1976; 14: 261–4.