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A cross-syndrome study of the development of holistic face recognition in children with autism, Down syndrome, and Williams syndrome

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ABSTRACT

We report a cross-syndrome comparison of the development of holistic processing in face recognition in school-aged children with developmental disorders: autism, Down syndrome, and Williams syndrome. The autism group was split into two groups: one with three high-functioning children and one with low-functioning children. The latter group has rarely been studied in this context. The four disorder groups were compared with typically developing children. Cross-sectional trajectory analyses were used to compare development in a modified version of Tanaka and Farah's part–whole task. Trajectories were constructed linking part–whole performance either to chronological age or to several measures of mental age (receptive vocabulary, visuospatial construction, and the Benton Facial Recognition Test). In addition to variable delays in onset and rate of development, we found an atypical profile in all disorder groups. These profiles were atypical in different ways, indicating multiple pathways to, and variable outcomes in, the development of face recognition. We discuss the implications for theories of face recognition in both atypical and typical development, including the idea that part–whole and rotation manipulations may tap different aspects of holistic and/or configural processing.

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Introduction

Faces have a special status as visual stimuli in terms of both their social relevance and the expertise that adults demonstrate in their recognition. Although infants show an early preference for faces (e.g., Johnson, Dziurawiec, Ellis, & Morton, 1991), investigation of the subsequent developmental course of face recognition has revealed different underlying processes and strategies that improve at different rates (e.g., Carey & Diamond, 1977; Freire & Lee, 2001; Maurer, Le Grand, & Mondloch, 2002). In this article, we focus on one of these processes, *holistic recognition,* and examine its developmental profile in typically developing (TD) children and children with three developmental disorders: autism, Down syndrome (DS), and Williams syndrome (WS).

Behavioral and neuroimaging experimentation has used several paradigms to investigate how individuals use visual information to recognize faces. These include (sometimes in combination) the manipulation of facial features such as eyes, mouth, nose, and facial outline; the presentation of these features in or out of the context of the face; the presentation of parts of faces such as the top or bottom half; and manipulation of the orientation at which the face is presented, for example, comparing upright and inverted presentations. Based on these paradigms, several processes have been identified and are broadly described as follows: (a) *holistic processing,* occasionally referred to as "global" or gestalt processing, where the face is recognized as a whole (holistic processing is sometimes conceived of in terms of a fast template-matching procedure [see also Diamond & Carey, 1986, for norm-based accounts; see Tanaka & Farah, 1993, and Tanaka & Sengco, 1997, for discussions of accounts based on the accessibility of different types of facial information]); (b) *featural processing,* also known as local or analytical face processing, where recognition is driven by individual features such as eyes, nose, and mouth; and (c) *configural processing,* where recognition is driven by the arrangement of the features in the face. This may be in terms of the relative positioning of the features, termed first-order configural information (e.g., eyes above nose), or in terms of the exact distances between features, termed second-order configural or relational information (e.g., eye separation). The contribution of these three processes to face recognition changes gradually with chronological age (CA), with configural processing being the last to emerge (Maurer et al., 2002; Mondloch, Le Grand, & Maurer, 2002).

In the following sections, we briefly review the research on holistic face recognition and its development and then consider the contrasting face recognition skills reported in the three developmental disorders.

Holistic face recognition

The role of parts and wholes in perception has long been a focus of research. The face is perhaps a unique example of a stimulus that is seen as an organized meaningful pattern that is difficult to break down into its parts without harming perception. Compelling examples of holistic processing come from two behavioral paradigms widely used to evaluate the existence of holistic face processing: the *part–whole* paradigm (Tanaka & Farah, 1993) and the *composite face effect* (Young, Hellawell, & Hay, 1987). In the part–whole paradigm, participants first memorize a set of target faces and learn names for them. They are then asked to identify features from one of the target faces (compared with a foil) presented either in isolation (e.g., "Which is Bill's nose?", where the foil is Bill's face with a different nose) or in the context of the whole face (e.g., "Which one is Bill?"). Stimuli are presented in either an upright or inverted orientation. Tanaka and Farah (1993) reported that adults were more accurate in recognizing individual features from the target face in the context of whole face (whole condition, 74%) than in isolation (part condition, 65%). However, when the stimulus was presented in an inverted orientation, recognition accuracy of features in the whole face decreased significantly (65%), whereas accuracy in the part condition was unaffected (64%). This pattern was not observed with other stimuli such as houses, where little difference was observed between the recognition of a house feature in the whole and part conditions (81% and 79%, respectively). These results are consistent with the idea that the upright whole face engages a fast template-matching recognition process that is unavailable for other stimuli or indeed for faces when they are inverted.

In the *composite face effect* paradigm (Young et al., 1987), individuals are presented with faces of famous people split into two along a horizontal axis. The top and bottom halves of the face come from different famous people, and the task is to recognize both individuals. The top and bottom halves of the face can be either aligned or misaligned with the top half of the face placed off center to the bottom part of the face. In this task, adults are worse at recognizing the faces when they are aligned than when they are misaligned. The interpretation is that the aligned halves engage holistic processing, reducing the individual's ability to identify parts of the face separately (see also Schiltz & Rossion, 2006, for comparable functional magnetic resonance imaging [fMRI] results).

In the two tasks, holistic processing plays a different role. In the part–whole task, the parts and whole are from the same face, so that holistic processing aids recognition. In the composite face task, the parts are from two distinct recognizable faces, so that holistic processing causes interference. That is, in the Tanaka and Farah's (1993) task, a face feature is recognized more accurately in the presence of the whole face, as if holistic processing boosts processing of individual features. In Young and colleagues' (1987) task, the two halves of the face are recognized less accurately when holistic processing is triggered, as if the component parts become fused, thereby making them harder to process individually. Nevertheless, the salient point is that in both of these cases, the opportunity to engage in upright whole-face processing results in a modulation of task difficulty. Indeed, the behavioral consequences of engaging holistic processing may depend on the exact nature of the task and on the face stimuli presented (Leder & Carbon, 2005).

Inversion, in contrast, generally causes poorer face recognition because it is held to disrupt both holistic and configural processing while leaving featural processing relatively unimpaired (see Rakover, 2002, for a review). Against the background of rotation invariance in general object recognition, the appearance of inversion effects has been used to chart the emergence of expertise in the recognition of visual stimuli that are usually presented in a canonical orientation such as faces and words. It has also led to the view that the special status of face recognition may reflect an expertise effect as well as (or instead of) face-specific processing properties (e.g., Bukach, Gauthier, & Tarr, 2006). The exact method by which inverted faces (and/or their component features) are recognized is unclear. It may involve mental rotation so that procedures tuned for upright recognition can be engaged, or it may involve different procedures that can recognize the face (or its features) in the inverted orientation (eyes and mouths, for instance, are broadly symmetrical around a horizontal axis and so less affected by inversion). Mental rotation would be implicated if the degree of rotation from upright (e.g., 90° vs. 180°) correlated with the disruption in performance. There is some evidence from fMRI that the recognition of inverted faces engages object processing rather than face processing areas (e.g., Yovel & Kanwisher, 2005).

Development of holistic processing in typical children

Young infants rapidly develop face recognition abilities, learning to detect gaze direction, facial gestures, and expressions of emotion within the first year of life. Indeed, research suggests that newborns preferentially orient toward face-like stimuli (e.g., Johnson et al., 1991), recognizing certain properties of faces from birth and distinguishing internal features by around the middle of the first year (see de Haan, 2001, for a review). Relatively few studies have examined the full developmental trajectory of holistic processing in TD children. There is some evidence that even young infants make use of holistic information in face recognition (Cohen & Cashon, 2001; Slater, 2000). For example, Cohen and Cashon (2001) habituated 7-month-olds to two female faces and then presented the infants with a pair of faces: one a familiar face and one a composite of the two habituation faces. When the faces were presented in an upright orientation throughout, the infants looked longer at the composite face than at the familiar face. However, when the faces were presented in an inverted orientation throughout, no such preference was observed. The authors concluded that the features of the habituation faces were processed independently in the inverted orientation, in which case both familiar and composite faces would contain familiar features and neither would appear to be novel. Most studies that used the part–whole and composite face paradigms have shown that holistic processing is apparent by 4 years of age (De Herring, Houthuys, & Rossion, 2007; Pellicano & Rhodes, 2003) and does not account for developmental changes in face recognition after 6 years of age (Carey & Diamond, 1994; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998).

Holistic processing in developmental disorders

The development of face recognition can be disrupted either by atypical experience, such as early visual deprivation, or by atypical developmental constraints present in some developmental disorders. For example, visual deprivation during early infancy due to congenital cataracts is associated with impaired performance on configural face processing tasks during childhood compared with controls (Le Grand, Mondloch, Maurer, & Brent, 2003), and atypical face encoding has been found in neurogenetic disorders such as fragile X and Turner syndrome (Garrett, Menon, MacKenzie, & Reiss, 2004; Lawrence, Kuntsi, Coleman, Campbell, & Skuse, 2003). In this study, we compared the development of holistic face processing in autism, DS, and WS. The motivation for such a comparison is that the disorders offer a window on the constraints that shape typical development because alterations of these constraints are viewed as the cause of deficits in face processing in the disorders (Annaz, Karmiloff-Smith, & Thomas, 2008; Karmiloff-Smith, 1998).

Autism

Autism is a common neurodevelopmental disorder characterized by impairments in social interaction, communication, and stereotypic behaviors (DSM-IV-TR [*Diagnostic and Statistical Manual of Mental Disorders,* 4th edition, text revision], American Psychiatric Association., 2000). The disorder is characterized in terms of a spectrum to capture differences in the severity of symptoms, IQ level, behavioral performance, and brain neuroanatomy (Caronna, Milunsky, & Tager-Flusberg, 2008; Pelphrey, Adolphs, & Morris, 2005; Rutter, 2005).

Abnormalities in face recognition in autism have been found using both behavioral and functional brain imaging techniques. In one of the first behavioral studies, children with autism were asked to recognize upright photographs of their peers. Two groups of children with autism, 9 and 14 years of age, appeared to perform similarly to controls matched on CA and performance IQ. However, when features of faces were selectively concealed, abnormalities in the face processing of the children with autism were revealed. Both younger and older participants with autism were significantly better than controls at identifying faces from the mouth area presented in isolation, and the younger participants with autism were significantly worse than controls at identifying faces from the eye region alone (Langdell, 1978). Other behavioral anomalies have been observed, including reduced attention to faces during infancy and deficits in the recognition of emotional expressions (e.g., Boucher & Lewis, 1992; Hobson, Ouston, & Lee, 1988; Klin et al., 1999; Osterling & Dawson, 1994; Teunisse & De Gelder, 1994). In TD children and adults, the eyes play an important role in face recognition. However, using an eye tracking method, Klin, Jones, Schultz, Volkmar, and Cohen (2002) found that individuals with autism focused more on the mouth region than on any other region of the face, with the eyes being of least interest (see also Joseph & Tanaka, 2003; Langdell, 1978). Overall, face recognition abilities in autism show a differential reliance on featural information. To the extent that these individuals rely on particular features such as the mouth rather than on the normal combination of features, one might view their recognition abilities as consistent with the "weak central coherence" theory of autism (Shah & Frith, 1983). Under this theory, there is a deficit in integrating information, with processing emphasizing perceptual detail to a greater extent than in TD children.

The behavioral decrement in face recognition ability is consistent with several functional imaging studies that have reported atypical or weak activation of the fusiform gyrus, an area that is activated during face recognition in normal adults (Critchley et al., 2000; Dalton et al., 2005; Schultz et al., 2000). Regions of the "social brain network," including the superior temporal sulcus and the amygdala, have also been found to exhibit atypical activation patterns in individuals with autism (Baron-Cohen & Belmonte, 2005; Hadjikani et al., 2004; Pelphrey et al., 2005). Recently, Koshino and colleagues (2008) found activation in a different location in the fusiform area in an adult sample with autism in response to faces compared with control participants. They also reported lower functional connectivity of fusiform areas with frontal areas, implying that the face recognition system resides in an abnormal cortical network (see also Hadjikhani, Joseph, Snyder, & Tager-Flusberg, 2007). However, the literature is somewhat inconsistent, with other studies reporting normal fusiform activation, that is, greater activation in response to familiar faces than to unfamiliar faces (e.g., Pierce, Haist, Sedaghat, & Courchesne, 2004). Findings from electrophysiological studies have indicated that individuals with autism exhibit atypical event-related brain potentials to faces, characterized by an absent or reduced N170 waveform component (one of the event-related potential markers for faces), with a more bilateral than right lateralized voltage distribution (Dawson et al., 2002; McPartland, Dawson, Webbs, Panagiotides, & Carver, 2004).

Two studies have directly examined holistic processing in high-functioning individuals with autism. Joseph and Tanaka (2003) employed the part–whole paradigm with 22 children with autism between 8 and 14 years of age, comparing them with TD children matched for CA. They reported that the advantage for recognizing features in the whole-face context was not modulated by group; no atypical part–whole effect was observed for the children with autism. However, they did report an anomalous pattern depending on feature; in the upright whole-face condition, the children with autism performed better when face identification depended on the mouth feature (70% vs. 60% in the mental-age-matched control group). When the mouth was the key feature, the children with autism also showed an inversion effect (accuracy fell to 47% vs. 49% in the control group). However, the children with autism performed poorly when face identification depended on the eyes in the upright condition (62% vs. 76% in controls) and showed no worse performance for eyes in the whole face condition when the stimuli were inverted (59% vs. a drop to 53% in controls).

Lopez, Donnelly, Hadwin, and Leekam (2004) employed a similar task with 17 adolescents with autism and 17 TD adolescents matched for CA. A target face was presented, and 500 ms later either two whole faces (one with a single feature changed) or two isolated features (one from the target face and one different). Participants needed to indicate the face or feature that matched the target face. Notably, the study employed a condition in which a cue accompanied the target face, alerting participants to the face feature relevant to subsequent matching. For the control group, the presence or absence of the cue did not serve to modulate the advantage of the whole-face condition over isolated features. However, in the autism group, a whole-face advantage was found only in the presence of the cue. The authors suggested that individuals with autism might be able to deploy holistic processing in face recognition under suitable cued conditions. However, it remains unclear why priming an individual feature should engage a process that serves to integrate features, thereby downplaying the independent identity of the features in a face.

In conclusion, existing evidence points to the availability of some holistic processing in autism but accompanied by feature-specific effects. Notably, the existing work is mostly restricted to high-functioning individuals with autism or Asperger syndrome. Thus, it is unclear whether these findings generalize to the spectrum as a whole (Frith, 2004). We address this question in the current study by the inclusion of two groups: one with low-functioning children with autism and one with high-functioning individuals, based on the Childhood Autism Rating Scale (CARS).

Williams syndrome

WS is a rare genetic disorder caused by a hemizygous microdeletion of 28 genes on chromosome 7q11.23 (Tassabehji, 2003). The incidence of WS is approximately 1 in 20,000 live births (Morris, Demsey, Leonard, Dilts, & Blackburn, 1988), although recent estimates have been higher (1 in 7500 live births [Stromme, Bjornstad, & Ramstad, 2002]). The main cognitive characteristics of WS include overall IQ levels ranging from 40 to 90 with the majority scoring between 55 and 69 (Mervis et al., 2000; Searcy et al., 2004), a "hypersocial" personality profile, relatively good face recognition and language skills compared with overall mental age (MA), but relatively poor visuospatial skills (Donnai & Karmiloff-Smith, 2000; Mervis & Bertrand, 1997; Udwin & Yule, 1991).

Face recognition abilities in WS have been a focus of heated debate during recent years. Tager-Flusberg, Plesa-Skwerer, Faja, and Joseph (2003) investigated holistic face recognition using the part–whole paradigm and the Benton Facial Recognition Test (Benton, Hamsher, Varney, & Spreen, 1983). A large group of 47 individuals with WS (age range = 12–36 years) and 36 CA-matched control participants were tested. In the upright condition, when the group was collapsed over the 24-year age range, the participants with WS showed a performance advantage when features were presented in the whole face, indicative of holistic processing. The authors reported that both WS and control groups performed best when the key facial feature that had been changed was the eyes. Overall, they concluded that holistic face processing in WS develops normally. However, in some experimental conditions, participants with WS were at floor level, rendering interpretation of the results more difficult.

And although performance on the Benton test was predominantly in the normal range for the WS group, the Benton test does not guarantee that recognition is achieved via normal processes given that many of the items can be solved by featural processing alone (Duchaine & Nakayama, 2004).

Indeed, several studies have suggested that relatively good face recognition behavior in WS is achieved by atypical underlying processes, in particular the preferential use of featural encoding leading to a reduced inversion effect (Deruelle, Mancini, Livet, Cassé-Perrot, & de Schonen, 1999; Karmiloff-Smith et al., 2004; Mills et al., 2000). The atypical behavioral evidence is complemented by findings from a small number of imaging and event-related potential (ERP) studies indicating anomalous brain activation during face recognition (Grice et al., 2001; Mobbs et al., 2004). However, the exact implications of these data for cognitive mechanisms are unclear. Grice and colleagues (2001) argued that differences in electroencephalographic gamma band oscillations compared with controls and with individuals with autism might suggest that, although both WS and autism rely more on featural processing in face recognition, the precise nature of featural processing differs between the two disorders.

In sum, the evidence on face recognition in WS remains mixed, with some arguments for normal development for holistic processing and other arguments for atypical development with a preference in WS for featural encoding, perhaps similar to, or perhaps different from, that found in autism.

Down syndrome

DS is a genetic disorder associated with the presence of three copies of chromosome 21 (trisomy 21) and is one of the most common sporadic genetic disorders (1 in 800 live births). Children with DS have overall IQ levels ranging between 36 and 107 but declining significantly with age to between 40 and 70 (Roizen & Patterson, 2003; Wang, 1996).

Only a handful of studies have examined face processing in DS, and these have mostly examined emotion recognition. Wishart and Pitcairn (2000) carried out two studies to investigate face recognition skills in children with DS. In their first study, 16 8- to 14-year-olds were tested on two tasks: identity matching and expression matching to a story. Their performance was compared with that of TD children matched on overall mental age (MA). Although children with DS were slower at identity-matching tasks, their accuracy was not significantly different from that of the MA-matched group. However, their performance was significantly poorer on the expression-matching task. Children with DS had particular difficulty in decoding emotions such as surprise and fear. Wishart and Pitcairn's other study also focused on identity and expression recognition. However, faces were now shown in either an upright or inverted position. Children were presented with familiar faces and unfamiliar ones and were asked to choose the face that they had seen before. Again, the results indicated that children with DS were less accurate and slower to response compared with MA-matched controls. Furthermore, unlike the TD group, the accuracy of the children in the DS group was not sensitive to the orientation of the faces (see also Williams, Wishart, Pitcairn, & Willis, 2005; Wishart, Cebula, Willis, & Pitcairn, 2007).

While showing relative deficits in face recognition, these studies provide little information on the face-encoding abilities of individuals with DS. The absence of an orientation effect might be viewed as indicating relatively weaker holistic and configural processing given that both are disrupted by this manipulation. Nevertheless, there are suggestions from other literature examining visuospatial skills in DS that there is a bias toward the holistic/global style of processing in the disorder. In a study comparing 7 children and adolescents with DS with 10 CA-matched individuals with WS, Bellugi, Lichtenberger, Mills, Galaburda, and Korenberg (1999) reported that in a drawing task, individuals with DS produced a good global pattern but failed to reproduce features correctly. Moreover, on the block design task, their performance was impaired by errors of internal detail. In the Delis Hierarchical Processing Test, where a large letter is made up of smaller letters, individuals with DS tended to reproduce only the global form of the large letter rather than the elements (Bihrle, Bellugi, Delis, & Marks, 1989). These studies predominantly used DS as a control group for studies on WS and so did not include separate MA- or CA-matched TD control groups (see, e.g., Wang, Doherty, Rourke, & Bellugi, 1995). Nevertheless, this work does suggest that face recognition might be a weakness in DS (e.g., a mean score of 15 on the Benton test for 11 adolescents with DS compared with 22 for a CA-matched group of 10 adolescents with WS [Wang et al., 1995]; cf. with our Table 1). It is possible, therefore, that when holistic face recognition skills are examined directly, children with DS may show an exaggerated part–whole effect.

Table 1
Test results per group. TD, typically developing; TD*, subset of the TD group approximately matched on CA to the atypical groups (n = 18); HFA, high-functioning children with autism; LFA, low-functioning children with autism; DS, Down syndrome; WS, Williams syndrome; CA, chronological age; BPVS, British Picture Vocabulary Scale; PC, pattern construction; Benton, Benton Test.

Group and sample size	Statistic	CA (months)	BPVS MA (months)	PC MA (months)	Benton raw score
TD	Mean	86	91	91	19
(n = 25)	Std	33	31	31	3
	Min	33	39	43	15
	Max	149	154	147	24
TD*	Mean	101	103	104	20
(n = 18)	SD	25	27	23	3
	Minimum	65	55	67	16
	Maximum	149	154	147	24
HFA	Mean	101	83	97	18
(n = 16)	SD	21	20	41	3
	Minimum	64	55	40	12
	Maximum	134	124	201	21
LFA	Mean	102	54	99	13
(n = 17)	SD	23	20	33	4
	Minimum	63	42	52	6
	Maximum	136	105	165	20
DS	Mean	114	46	38	14
(n = 15)	SD	25	6	4	2
	Minimum	74	40	34	11
	Maximum	157	62	49	19
WS	Mean	105	78	42	20
(n = 15)	SD	25	23	10	2
	Minimum	68	38	34	15
	Maximum	145	124	64	24

Aims of the current study

The goal of the current study was to compare the development of holistic face processing in our four disorder groups (high-functioning autism, low-functioning autism, WS, and DS) for children between 5 and 12 years of age. The atypical patterns of face processing previously outlined for each disorder are viewed as the outcome of altered constraints operating on the development of face recognition abilities. Therefore, performance should be studied within a developmental framework. Ideally, this should be done longitudinally, but in the first instance profiles of development can be approximated by cross-sectional studies. To assess holistic processing, we adopted the part–whole paradigm used by Tanaka and Farah (1993) with some minor modifications. We then used developmental trajectory analyses to compare the change in performance across age observed in each group as well as the relation between performance and various measures of MA (Thomas et al., in press).

Tanaka and Farah's (1993) part–whole task involves two manipulations to assess holistic processing: recognition of features presented in isolation versus in the context of a whole face and presentation of the stimuli in upright orientation versus inverted orientation. Lewis and Glenister (2003) employed three different orientations in their investigations of face processing: upright, a 90° clockwise rotation, and inverted. We also used these three orientations to increase the sensitivity of our rotation manipulation. Thus, we added the 90° orientation to the Tanaka and Farah design.

The Tanaka and Farah (1993) paradigm also included a memory component. Participants were required to memorize a small set of target faces, and then immediately following learning the two-choice recognition test was administered. The context in which a feature was presented (whole face vs. isolated) was, therefore, a manipulation that targeted the adequacy of the feature (plus context) as a *retrieval cue* for a memorized face. However, using this paradigm, Joseph and Tanaka (2003) reported that they needed to exclude 11 (33%) of their autism sample because those individuals were "unable to comply and/or attend sufficiently to successfully complete the training procedure" (p. 535). The excluded children had a mean full-scale IQ of 74 and, therefore, represented less able children with autism. To test younger and less able children, we simplified the paradigm in the following way. Instead of requiring the children to memorize, say, Bill's face and then asking them to recognize Bill/Bill's eyes, all stimuli were presented simultaneously; two features (part condition) or faces (whole condition) were presented below a target face, and children were asked to indicate which of the two alternatives matched the target (either the relevant feature or the whole face). The removal of the memory component focused the task on visual recognition processes and addressed the concern that impairments in verbal and visuospatial short-term and/or long-term memory have been reported in all three disorders under study (e.g., Jarrold, Baddeley, & Phillips, 2002; Minshew & Goldstein, 2001; Sampaio, Sousa, Fernandez, Henriques, & Goncalves, 2008). Nevertheless, the basic structure of the paradigm was retained to evaluate holistic processing, that is, whether the recognition of a feature was modulated by presentation in whole-face context versus in isolation.

In most of the disorder studies reviewed in the previous section, the experimental design involved matching the disorder group to a TD control group based on CA or MA. However, these designs give little sense of how holistic processing or task performance develops with age, in some cases collapsing performance over wide age ranges. In the current study, we used trajectory analyses in a cross-sectional design to explore how performance in each disorder changed across age (Thomas et al., in press). A trajectory that links changes in performance to CA establishes whether a disorder group shows any behavioral deficit on the experimental task and provides a theory-neutral comparison of typical and disorder groups. Trajectories linking performance to measures of MA indicate whether any behavioral deficit in the disorder group is in line with the developmental state of other aspects of the cognitive system. The study of such *developmental relations* is theory dependent in that it relies on theoretical considerations regarding the tests of MA that are relevant to the cognitive domain under study. Trajectory analysis is directly analogous to the more familiar analysis of variance (ANOVA) but employs the intercepts and gradients of linear regressions rather than group means. The method relies on the availability of reasonable participant numbers across the range of CA and MA measured and of an experimental task that is sensitive across this range.

The part–whole task permits assessment of the presence of holistic processing (whether identification of a face feature is modulated by presenting it in isolation or in the context of a whole face), the role of orientation (whether the holistic processing effect is modulated by presenting the stimuli in an upright, 90°, or inverted orientation), and whether any such effects are modulated by the nature of the target feature (e.g., eyes, nose, mouth). Based on our review of the literature for the three disorders, we generated the following predictions regarding the possible patterns that would be observed. We anticipated that all three disorders would show some evidence of holistic processing via the part–whole manipulation. In autism, we expected feature-specific effects with decreased performance when eyes were the target feature. For both autism and WS, we anticipated a possible reduction in the effects of inversion due to a greater reliance on featural processing. The literature predicts this similarity despite the fact that, in many respects, autism and WS are contrasting disorders; autism exhibits social disengagement, whereas WS shows elevated social engagement. Given the absence of much research on low-functioning children with autism, we were neutral with regard to our predictions. For DS, we predicted an increase in the size of the holistic effect based on their observed visuospatial processing style.

Method

Participants

Participants were 33 children with autism (28 boys and 5 girls, mean age = 8 years 6 months), 15 children with DS (10 boys and 5 girls, mean age = 9 years 6 months), 15 children with WS (7 boys and 8 girls, mean age = 8 years 9 months), and 25 TD children (13 boys and 12 girls, mean age = 7 years 2 months). See Table 1 for group details. The greater age range of the TD sample permitted comparisons to be made between disorder and TD trajectories on the basis of either CA or MA where disorder groups may have lower MAs. All of the children in the group with autism met established criteria for autism such as those specified in the DSM-IV (American Psychiatric Association, 2000) and the Autism Diagnostic Observation Schedule (ADOS) (Lord, Rutter, DiLavore, & Risi, 1999). The gender bias for the autistic groups was characteristic of the disorder (Baird et al., 2006). Children in the DS group had previously tested positive for trisomy of chromosome 21. Children with WS had been diagnosed clinically as well as by means of the fluorescence in situ hybridization (FISH) genetic test for microdeletion of specific gene markers. Participants were recruited from north London schools and, for WS, via the Williams Syndrome Foundation (UK). All individuals had normal or corrected-to-normal vision. The experimental protocol was approved by the Birkbeck College, University of London ethics committee prior to recruitment of participants. Both parental informed consent and the children's assent were obtained before participation.

Each child was examined on the following standardized tests: the British Picture Vocabulary Scale (BPVS) (Dunn, Whetton, & Pintilie, 1997), the Pattern Construction (PC) test from the British Ability Scales–2nd edition (BAS-II) (Elliott, Smith, & McCulloch, 1996), and the Benton Facial Recognition Test (henceforth Benton) (Benton et al., 1983). For the TD group, CA predicted 93% of the variance in BPVS MAs, 85% of the variance in PC MAs, and 85% of the variance in Benton raw scores, confirming that this group was representative of the TD population. Children in the autism group were also assessed on the CARS (Schopler, Reichler, & Rochen, 1993). This test has the advantage of offering a continuous scale for the severity of autistic symptoms (see Rellini, Tortolani, Trillo, Carbone, & Montecchi, 2004). On the basis of CARS scores, the overall autism group was divided into a low-functioning group (defined as CARS range 37–60 points, 15 boys and 2 girls, mean age = 8 years 6 months) and a high-functioning group (CARS range 30–36 points, 13 boys and 3 girls, mean age = 8 years 5 months) (see Appendix Table A for details). Henceforth, the two autism groups are referred to as HFA for the high-functioning group and LFA for the low-functioning group. The split according to symptom severity also produced two groups with a significant difference in language ability of 28.4 months, $t(31) = 4.08$, $p < .001$. Details of all participant groups can be found in Table 1. For the trajectory methodology, MAs are used as predictors to investigate developmental relations between cognitive abilities. The frequency distribution of MAs exhibited by each group for each of the measures is depicted in Appendix Table B.

Stimuli

Three high-quality grayscale faces were generated using Faces 3.0 software (IQ Biometrix). For each prototype face, two types of eyes, nose, and mouth were used, generating 18 unique faces. The use of this face reconstruction software meant that factors such as cropping and positioning of the face features were eliminated as potential confounds while still generating reasonably realistic looking faces. Also, similar shape features and eye color were chosen for each presented set of faces to reduce the possibility of confounding the test due to stimuli choice. Fig. 1 shows an example of the stimuli.

Procedure

A target face was presented on a screen, below which were two stimuli that were either whole faces (Fig. 1A) or isolated face features (eyes, nose, or mouth) (Fig. 1B). One stimulus (with the side counterbalanced) was the same as the target (or the relevant feature of the target), whereas the other stimulus differed in the given feature (eyes, nose, or mouth). Participants were required to identify whether either the face or the feature was the same as the target face.

Stimuli were presented on a 17-inch touch-screen computer monitor using SuperLab Pro 2.0 software. Children were seated facing the computer monitor at a viewing distance of approximately 30 cm with their eye level at the center of the screen. Each child was tested individually and first took part in a practice task consisting of 6 trials (3 whole-face and 3 part-face trials) where feedback was given to familiarize them with the testing procedure and the touch-screen equipment. Participants were informed that identification of the face by a single feature was necessary in some of the trials.

The experimenter initiated the task with the following instructions: now we are going to play a game. Look at this face [experimenter points to the target face]. *Can you touch the face that you think looks the same? Sometimes you will see the face and features such as eyes, nose, or mouth. Can you show me which feature is the same as in the face? Are you ready? Try to answer as fast as possible.*

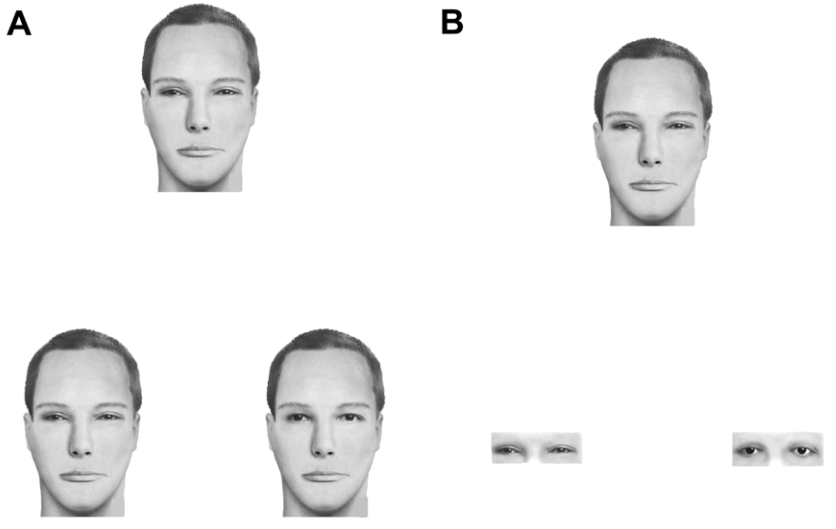

Fig. 1. Example of the whole–part stimuli. (A) Whole-face condition. (B) Part-face condition. The upper face is the target. Participants needed to decide which of the lower alternatives matched the target face.

All participants were tested on 36 upright trials (18 whole-face and 18 part-face trials), followed by 36 trials in 90° orientation (clockwise rotation) and by 36 inverted trials. The trial order was randomized within orientation blocks (part–whole), but the block order was fixed (orientation). In fixing the block order, we followed previous studies that began with upright face trials to maximize the ecological validity of the face recognition task and blocked orientation to allow children to develop recognition strategies for each orientation (e.g., Le Grand et al., 2003; Mondloch et al., 2002; Yovel & Kanwisher, 2008). A fixed order of blocks risks confounding orientation effects with order effects in the results, for example, if there is poorer performance on later blocks due to lack of attention. To mitigate this risk, children were given short breaks between each block and were continuously monitored for signs of tiredness. Additional breaks were given if necessary. Children made responses by touching the relevant face or face feature on the touch-screen. Before and after each response, a fixation cross appeared, giving the experimenter an opportunity to check whether the child was becoming tired or distracted. The only feedback given during the test trials was nonspecific praise. Accuracy and response time were recorded.

Results

The results are provided in three sections. First, we assess how well the children in each group recognized faces. Second, we explore the development of part–whole processing and its sensitivity to inversion using trajectory analysis. Third, we explore any differential effects of the target feature (eyes, nose, or mouth) on responses for the groups.

Face recognition ability

Face recognition ability was assessed via the Benton test (Benton et al., 1983). This test has not been standardized against a full normal developmental sample and has limitations as a test of face recognition ability because accurate performance can be achieved using feature-based strategies (Duchaine & Nakayama, 2004). Nevertheless, it is often used in the literature, and raw scores provide an indication of the relative abilities of the groups. For the full TD group, the raw score exhibited a linear increase with CA, with age accounting for 85% of the variance, $F(1, 23) = 140.32$, $p < .001$. For a direct comparison of the overall performance of each group, we used a restricted sample of the TD group ($n = 18$) so that the CAs of the five groups were approximately matched (t tests, all $p > .50$). The mean performance levels are included in Table 1.

In line with previous results, the WS group performed on a par with the TD group (t test, $p > .50$). All of the other groups produced reliably lower face recognition scores on the Benton test (HFA vs. TD: $t(32) = 2.61$, $p = .014$; LFA vs. TD: $t(33) = 5.99$, $p < .001$; DS vs. TD: $t(31) = 7.53$, $p < .001$). The LFA and DS groups performed more poorly than the HFA group but did not differ reliably from each other ($p > .50$). More severe levels of autism, therefore, produced much lower scores on the Benton test. One possibility is that the LF children with autism were unable to engage in experimental tasks of this nature. However, Table 1 indicates that although the LFA group also scored poorly on the BPVS (mean MA of 4 years 6 months compared with their CA of 8 years 6 months), they nevertheless scored at CA-level expectations on the pattern construction test. This demonstrates that these children could engage in test situations and increases confidence that scores on the other measures were an accurate reflection of their abilities. Lastly, it was notable that on the Benton test, children with DS scored as poorly as the LFA group despite the fact that a marked deficit in social cognition is not predominantly associated with DS (Kent, Evans, Paul, & Sharp, 1999).

Trajectories of part–whole processing

We constructed cross-sectional trajectories on the part–whole paradigm to assess the development of holistic processing in the TD children, initially focusing on accuracy data. Performance was modeled by a linear trajectory relating accuracy to CA. The two experimental manipulations of *part–whole* (feature presented in isolation vs. feature presented in the context of a face) and *stimulus orientation* (upright, 90°, or inverted) yielded a 2×3 design and, therefore, six trajectories linking accuracy with age for each group. These trajectories are depicted in Fig. 2. Cross-sectional trajectory analyses permit the comparison of linear functions within groups, between groups, or in mixed designs. They are analogous to analysis of variance except that linear regressions are compared instead of cell means (Thomas et al., in press). A linear regression is represented by an intercept and a gradient. Differences in intercepts correspond to delays in the onset of development while differences in gradient correspond to slower or faster rates of development. For clarity, individual data points are not shown; R^2 values indicate the proportion of variability explained by each trajectory.

Typically developing control group analyses by chronological age

The accuracy data were analyzed using a repeated-measures fully factorial analysis of covariance (ANCOVA) with two within-participant factors of *part–whole* and *orientation.* A third within-participant factor of *feature* was excluded to simplify the analyses and because the effects of feature were constant across age (i.e., did not interact with age or any measure of MA). A fully factorial ANCOVA includes all interaction terms between the covariate, within-participants factors and between-participants factors. Feature effects are reported in a separate section. Main effects of repeated-measures factors are independent of the between-participant covariate of age; therefore, pure repeated-measures effects are reported from an analysis that excludes the covariate, and so degrees of freedom may differ for pure repeated-measures effects and between-participant effects or interactions.[1]

In TD children, performance on the task improved reliably with age, $F(1, 23) = 47.28$, $p < .001$, $\eta_p^2 = .678$. Most strikingly, and in contrast to Tanaka and Farah (1993), children found the part (isolated feature) condition easier than the whole-face condition in the modified part–whole task, F(1,

[1] Main effects of repeated-measures factors are independent of the between-participant covariate of age in the sense that participants have the same age when they generate each of their repeated scores. For example, if Jane scores 4 on Task A and 10 on Task B, her repeated-measures task effect is +6. This difference in the main effect of the repeated measure does not depend on Jane's age. Note also that the +6 task effect is not altered if Jane is entered into a trajectory analysis according to her CA or MA; the two scores she contributes remain the same in each case. However, if there were an interaction between the covariate (age) and the repeated measure (perhaps the task effect is larger at younger ages than at older ages), the choice of age covariate clearly matters. Is a task difference of +6 appropriate for Jane's CA or for her MA? The presence of the task by age interaction is tested in the ANCOVA.

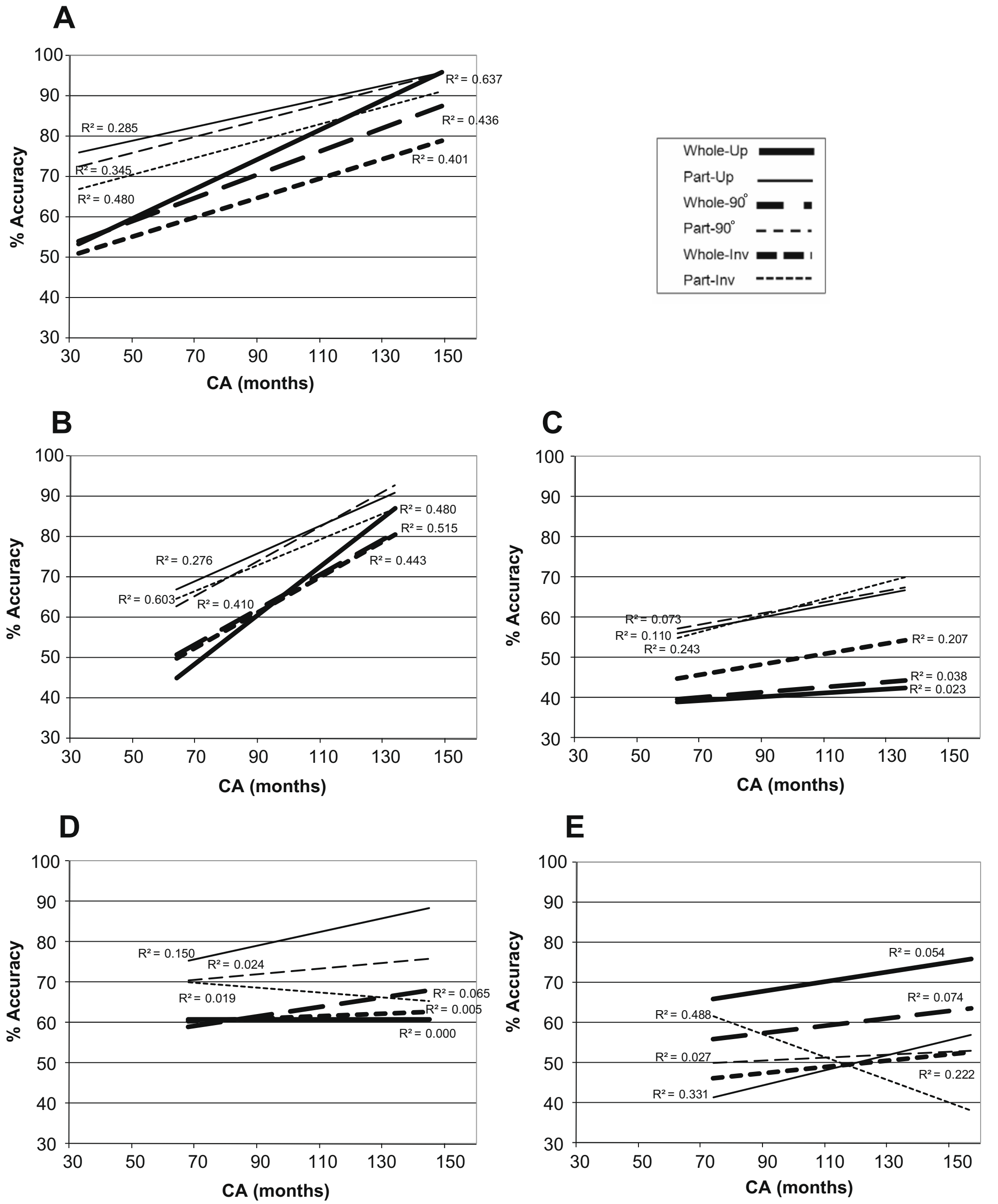

Fig. 2. Developmental trajectories for accuracy scores on the part–whole task for each participant group plotted against chronological age (in months). (A) TD group. (B) HFA group. (C) LFA group. (D) WS group. (E) DS group. R^2 values indicate the proportion of variance explained by each trajectory. Inv, inverted.

24) = 36.90, $p < .001$, $\eta_p^2 = .606$. To the extent that modulation by part–whole is an index of holistic processing, this mode of processing was apparent from the earliest age tested. Rotation away from upright presentation reduced the accuracy of performance, $F(1, 24) = 26.11$, $p < .001$, $\eta_p^2 = .521$.

Although the overall rotation effect was reliable, and the accuracy level for the 90° condition fell intermediate between upright and 180°, pairwise comparison did not reveal reliable differences between upright and 90° conditions or between 90° and 180° conditions. Notably, rotation affected the part and whole conditions differently. In the part condition, rotation had the same effect across the age range, whereas in the whole condition, the rotation effect emerged across development. This produced a reliable three-way part–whole by orientation by age interaction, $F(1, 23) = 4.70$, $p = .041$, $\eta_p^2 = .170$. The emerging rotation effect for whole faces is consistent with a specialized template-matching process for recognizing upright faces that emerges with age. However, this result must be interpreted with caution because the interaction could also be produced by a floor effect in the whole condition at younger ages. In our study, holistic processing disadvantaged the children in identifying individual features. The disparity likely stems from differences in task design compared with the original Tanaka and Farah paradigm, most probably the absence of a memory component in our task. Our results are more consistent with the composite face effect, in which holistic processing makes identification of elements harder by fusing them into a new whole. We return to this point in the Discussion.

Disorder group analyses

We are now in a position to compare the performance of each disorder group against the typical pattern of development. The comparison was carried out in two ways. First, for each disorder group, we constructed the development trajectories relating performance to CA and compared this pattern with the TD trajectory. Second, we constructed developmental trajectories relating performance to MA, derived either from the BPVS or from the pattern construction test. Because the Benton test does not generate an MA equivalent, these trajectories were constructed between part–whole performance and the raw score on the Benton test.

Respectively, the CA and MA analyses allow us to evaluate (a) the nature of any deficit compared with the TD group and (b) potential developmental relations within each disorder between part–whole performance and different cognitive abilities when performance did not reach age-level expectations. The advantage of CA as a predictor is that it gives a theory-neutral test for the presence of deficit in each disorder group, whereas the use of MA as a predictor depends entirely on the validity of the theoretical assumption that the chosen MA measure is pertinent to the experimental task. The disadvantage is that CA is often not a good predictor of performance in developmental disorders due to variations in severity in different children that are not necessarily correlated with their age. In the current case, however, we will see that broadly the same pattern of results emerged from both CA and MA analyses.

Chronological age as the predictor

The trajectories for each disorder were first analyzed in isolation using the same method as with the TD group. The pattern exhibited by each disorder group was then compared with the TD pattern using a mixed-design ANCOVA. The first analysis was carried out because in the combined analysis differences in variability between the groups can sometimes mask effects that are present in a single group. We performed three planned comparisons to (a) assess the effect of the severity of autistic symptoms (measured according to the CARS test) on face recognition by comparing the HFA and LFA groups, (b) examine whether the WS and HFA groups responded in a similar way in the part–whole task given that they have previously both been characterized as having a “featural” approach to face recognition, and (c) contrast the DS and LFA groups to examine whether face recognition was poor in a similar way given that both groups had similar low levels of performance on the Benton test.

For between-group comparisons, age was rescaled to count in months from the youngest age measured in the disorder group when constructing the trajectories. This ensured that group differences were evaluated at the onset of development (the beginning of the trajectory); effects and interactions of the covariate then indicated whether this difference changed with age. For one measure, the full TD group did not score as poorly as three of the disorder groups (on the Benton test compared with the HFA, LFA, and DS groups). Trajectory analyses require that comparisons be made at a point of overlap between any two trajectories because extrapolation outside of the measured age range has poor validity. For these three comparisons, the age covariate was rescaled to count from the lowest performance of the TD group rather than the disorder group.

High-functioning autism group: The developmental trajectories for the HFA group are shown in Fig. 2B. Performance improved reliably with age in this group, $F(1, 14) = 30.45$, $p < .001$, $\eta_p^2 = .685$, and as with the TD group, individuals found the part condition to be easier than the whole condition so that placing features in context made them harder to discriminate, $F(1, 15) = 20.08$, $p < .001$, $\eta_p^2 = .572$. However, accuracy was independent of the stimulus orientation, $F(1, 15) = 1.80$, $p = .200$, $\eta_p^2 = .107$. Similarly, there was no three-way interaction indicating the emergence of an orientation effect in the whole condition across age, $F(1, 14) = 0.27$, $p = .610$, $\eta_p^2 = .019$. It is possible that the three-way interaction in the TD group could be a floor effect for the youngest children attenuating the effect of orientation in the whole condition. However, when TD participants with ages younger than those found in the HFA group were eliminated from the analysis, the three-way TD interaction still remained at borderline significance, $F(1, 16) = 4.34$, $p = .054$, $\eta_p^2 = .213$. For comparably aged children, then, the HFA group demonstrated no indication of an equivalent three-way interaction. Direct comparison with the TD group indicated that although development in the HFA group was delayed in its onset (main effect of group: $F(1, 37) = 15.43$, $p < .001$, $\eta_p^2 = .294$), it increased at a faster rate (group by age interaction: $F(1, 37) = 5.01$, $p = .031$, $\eta_p^2 = .119$). The absence of an orientation effect was supported by a reliable group by orientation interaction, $F(1, 37) = 4.15$, $p = .049$, $\eta_p^2 = .101$.

Low-functioning autism group. The trajectories for the LFA group are depicted in Fig. 2C. Here, too, performance increased reliably with age, $F(1, 15) = 5.14$, $p = .039$, $\eta_p^2 = .255$, and individuals found the part condition to be easier than the whole condition, $F(1, 16) = 4.70$, $p < .001$, $\eta_p^2 = .801$. Unlike the HFA group, these children were sensitive to the orientation of the stimuli but, importantly, performed better for inverted stimuli than for upright or 90° stimuli, $F(1, 16) = 11.24$, $p = .004$, $\eta_p^2 = .413$. Moreover, this difference stemmed from the whole condition (part–whole by orientation interaction: $F(1, 23) = 4.70$, $p = .041$, $\eta_p^2 = .170$). That is, children in the LFA group found the task to be easier when the whole faces were presented upside down, whereas for individual features the orientation did not matter. Comparison with the TD group suggested a delayed onset in development (main effect of group: $F(1, 38) = 48.89$, $p < .001$, $\eta_p^2 = .563$) but improvement with age at a broadly comparable rate (group by age interaction: $F(1, 38) = 3.16$, $p = .084$, $\eta_p^2 = .077$). The reverse inversion effect in the LFA group produced a significant group by orientation interaction, $F(1, 38) = 5.35$, $p = .026$, $\eta_p^2 = .123$.

Comparison of HFA and LFA groups. Direct comparison of the HFA and LFA groups indicated that at onset the trajectories were at a comparable level, $F(1, 29) = 3.46$, $p = .073$, $\eta_p^2 = .107$, but performance in the HFA group increased much more quickly with age, $F(1, 29) = 10.77$, $p = .003$ $\eta_p^2 = .271$. The difference in the inversion effect was not reliable (group by orientation interaction: $F(1, 29) = 0.05$, $p = .825$, $\eta_p^2 = .002$). In sum, the greater severity of autistic symptoms was associated with slower development on the task and a relatively greater disadvantage in processing upright whole faces compared with TD children. The TD group showed an advantage for upright whole faces; in the HFA group the advantage disappeared, whereas in the LFA group inverted faces were now better. However, direct comparison revealed that the autistic groups were not completely distinct in the latter regard.

Williams syndrome. Fig. 2D shows the trajectories for the WS group. Unlike the autistic groups, performance on the part–whole task did not significantly improve with age, $F(1, 13) = 0.59$, $p = .456$, $\eta_p^2 = .043$. As with the TD group, features were discriminated better in isolation and better when presented in an upright orientation (part–whole: $F(1, 14) = 26.17$, $p < .001$, $\eta_p^2 = .651$; orientation: $F(1, 14) = 8.98$, $p = .010$, $\eta_p^2 = .391$). However, for the WS group, stimulus rotation primarily affected the part condition rather than the whole condition (part–whole by orientation interaction: $F(1, 14) = 6.97$, $p = .019$, $\eta_p^2 = .332$). Direct comparison with the TD group indicated no delay in onset in the WS group, $F(1, 36) = 2.46$, $p = .125$, $\eta_p^2 = .064$, but a reliably slower rate of development, $F(1, 36) = 6.43$, $p = .016$, $\eta_p^2 = .152$. The fact that inversion increasingly affected whole-face discrimination with age in the TD group, whereas inversion consistently affected part-face discrimination in the WS group, led to a significant four-way group by orientation by part–whole by age interaction, $F(1, 36) = 4.66$, $p = .038$, $\eta_p^2 = .115$. If one views the inversion effect as a marker for the emergence of a specialized template-matching process for recognition, in the WS group this appeared to occur for processing face features rather than whole faces.

Comparison of WS and HFA groups. Of the disorder groups, WS and HFA performed best on the Benton test. Did they perform in a comparable way on the part–whole task? Direct comparison yielded only a difference in the rate at which the two groups were developing, with the WS group improving more slowly, $F(1, 27) = 12.53$, $p = .001$, $\eta_p^2 = .317$. Note, however, that the WS group scored higher on the Benton test than did the HFA group. This may imply that the processing strategy in the HFA group is optimized earlier than that in the WS group.

Down syndrome. As with the WS group, performance on the part–whole task in the DS group did not improve reliably with age, $F(1, 13) = 0.56$, $p = .468$, $\eta_p^2 = .041$, as shown in Fig. 2E. In marked contrast to the TD group and all other disorder groups, the children with DS performed better in the whole-face condition than in the part-face condition, $F(1, 14) = 20.85$, $p < .001$, $\eta_p^2 = .598$. Although these children demonstrated a strong effect of orientation, $F(1, 14) = 18.95$, $p = .001$, $\eta_p^2 = .575$, its pattern of influence was complex. For whole faces, there was a consistent effect across the age range, with best performance in the upright presentation, intermediate performance at the 90° presentation, and worst performance in the inverted presentation. For the part-face condition, the pattern changed with age, with an initial advantage for inverted features and a later advantage for upright features (part–whole by orientation by age interaction: $F(1, 13) = 5.14$, $p = .041$, $\eta_p^2 = .283$). Direct comparison with the TD group confirmed the opposite direction of the part–whole effect in the DS group (group by part–whole interaction: $F(1, 36) = 13.72$, $p = .001$, $\eta_p^2 = .276$) and the anomalous interaction of part–whole and orientation conditions across age (four-way interaction including group: $F(1, 36) = 10.98$, $p = .002$, $\eta_p^2 = .234$). In addition, the comparison indicated a delayed onset of performance in DS, $F(1, 36) = 40.84$, $p < .001$, $\eta_p^2 = .531$, and a slower rate of development, $F(1, 36) = 9.54$, $p = .004$, $\eta_p^2 = .209$. In sum, the DS group appeared to be particularly reliant on whole-face processing and exhibited an atypical strategy in feature-based discrimination.

Comparison of DS and LFA groups. Lastly, the DS and LFA groups exhibited comparably poor performance on the Benton test. As the preceding paragraphs suggest, this was not associated with comparable performance on the part–whole task. First, although the trajectories began at the same level and increased at the same rate (group: $F(1, 28) = 1.32$, $p = .260$, $\eta_p^2 = .045$; group by age interaction: $F(1, 28) = 1.28$, $p = .268$, $\eta_p^2 = .044$), the DS group was more accurate in the whole-face condition than in the part-face condition, whereas the LFA group showed the opposite pattern (group by part–whole interaction: $F(1, 28) = 14.41$, $p = .001$, $\eta_p^2 = .340$). Second, inversion helped the LFA group in the whole-face condition but hindered the DS group (group by orientation interaction: $F(1, 28) = 15.92$, $p < .001$, $\eta_p^2 = .362$). Third, inversion modulated the part-face condition in the DS group but had no effect on the part-face condition in LFA (group by part–whole by orientation interaction: $F(1, 28) = 24.87$, $p < .001$, $\eta_p^2 = .470$). The implication is that similar (low) performance on the Benton test can be generated either by a system that relies on whole face processing and performs best on upright faces (DS group) or by a system that relies on featural processing and performs poorest on upright faces (LFA group).

Mental age as the predictor

We next explored how well three different measures of MA predicted performance in the part–whole task. These were BPVS (receptive vocabulary), PC (visuospatial construction), and the Benton test.[2] The effect of replacing the predictor of CA with MA is to move a disorder group down the age range should these children exhibit a deficit for a given skill. In the following analyses, we summarize the effects observed in the CA analyses and then indicate whether replacing CA with each MA measure altered the pattern of results for a given disorder. Note that if for some disorder performance on the part–whole task is in line with these children's level of development in another cognitive domain (e.g., language), plotting the group's trajectory according to an MA measure of that domain (e.g., BPVS) should normalize the pattern of development. The disorder group's pattern should become indistinguishable from the TD pattern.

[2] We used the Benton raw score as the predictor in these analyses. This is because the Benton raw score showed a correlation of .92 with CA in the TD group. A relationship of raw score = .092 × age (in months) + 11.1 explained 85% of the variance. The raw score, therefore, can serve as a proxy for MA in face recognition.

High-functioning autism. The principal features of the CA trajectory for the HFA group were a reliable improvement with age, an advantage for part-face discrimination, but an absence of the inversion effect. Compared with the TD group, the HFA group showed a delay in onset but a faster rate of development. Fig. 3 shows trajectories for all groups plotted against BPVS MA. For the HFA group, MA according to the BPVS did not predict part–whole performance any more strongly than did CA, $F(1, 14) = 6.55$, $p = .023$, $\eta_p^2 = .319$. However, the differences in onset and rate compared with the TD group both disappeared ($p > .40$). The main effects of repeated measures (presence of part advantage

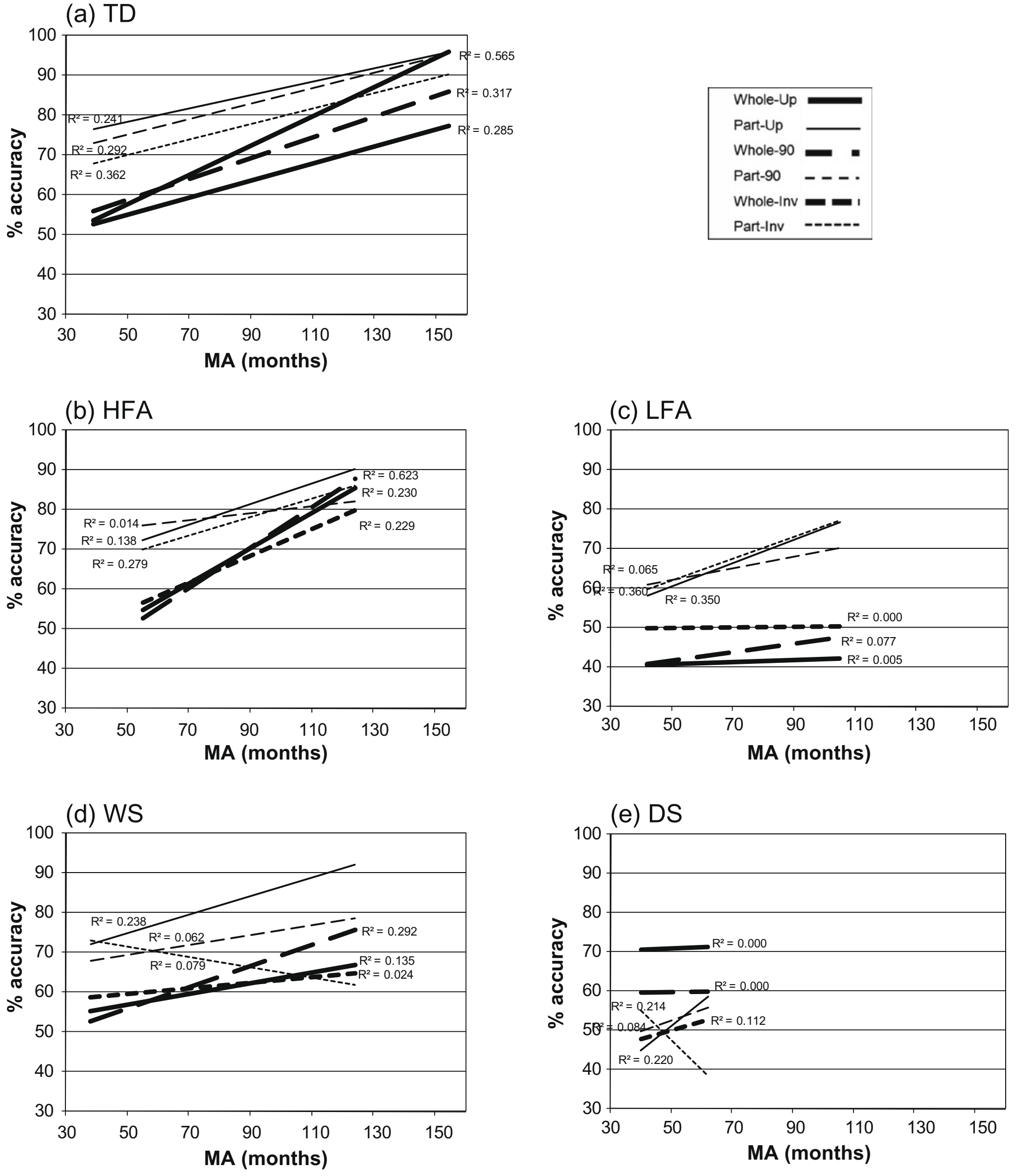

Fig. 3. Trajectories for all groups when plotted against BPVS mental age. (A) TD group. (B) HFA group. (C) LFA group. (D) WS group. (E) DS group. The BPVS is a standardized test of receptive vocabulary. Inv, inverted.

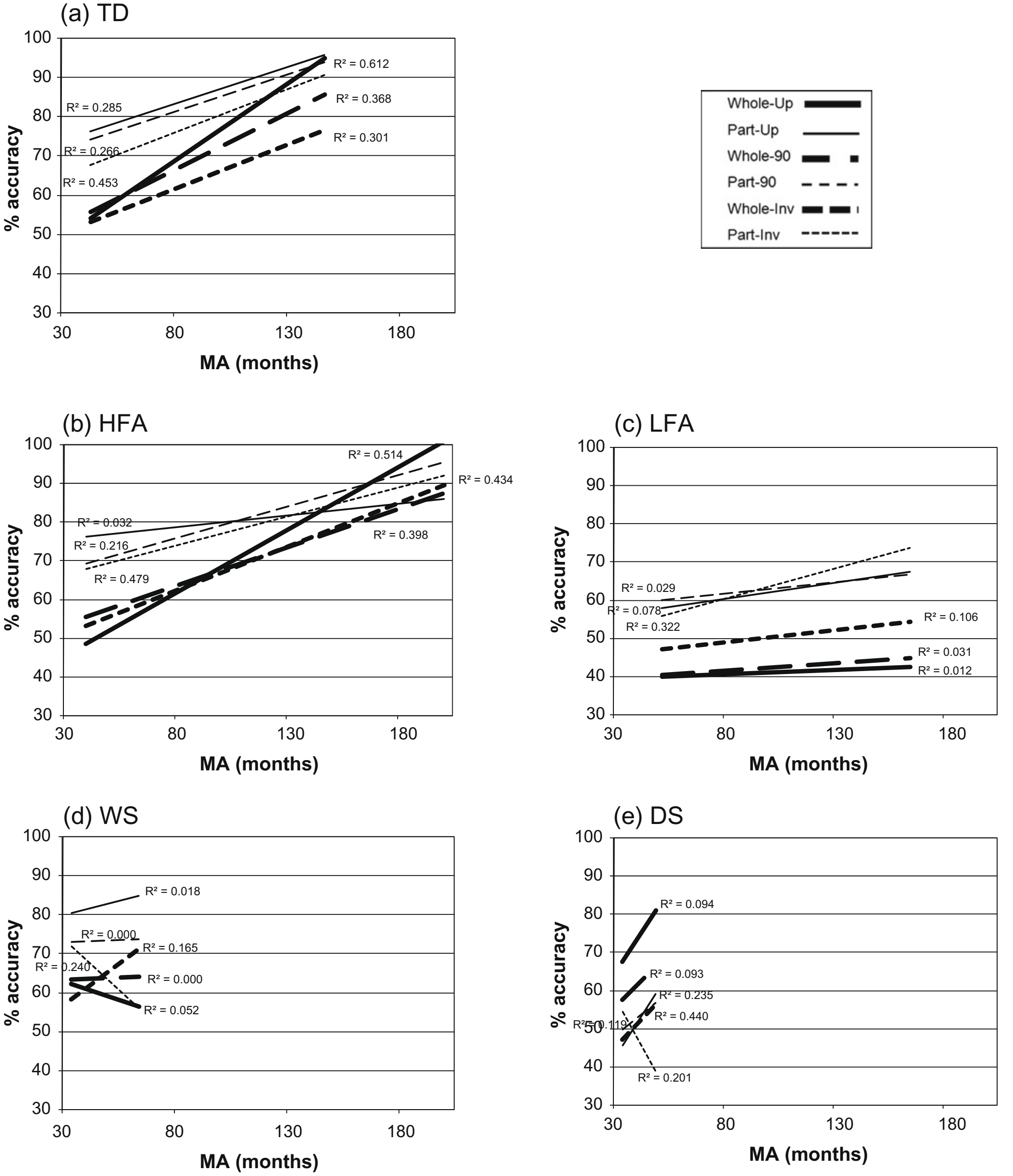

Fig. 4. Trajectories for all groups when plotted against Pattern Construction mental age from the BAS-II. (A) TD group. (B) HFA group. (C) LFA group. (D) WS group. (E) DS group. Pattern construction is a standardized test of visuospatial cognition. Inv, inverted.

and absence of inversion effect) are independent of the covariate of age and so are unaffected by shifting to an MA measure (see note 1). A similar picture emerged when PC MA and the Benton raw score were used to predict performance, as shown in Figs. 4 and 5, respectively. Neither served as a better predictor of performance than did CA (PC: $F(1, 14) = 12.98$, $p = .003$, $\eta_p^2 = .481$; Benton: $F(1, 14) = 22.81$, $p < .001$, $\eta_p^2 = .620$; cf. CA: $F(1, 14) = 30.45$, $p < .001$, $\eta_p^2 = .685$). Both predictors eliminated differences compared with the TD group in onset and rate. In sum, constructing the trajectories

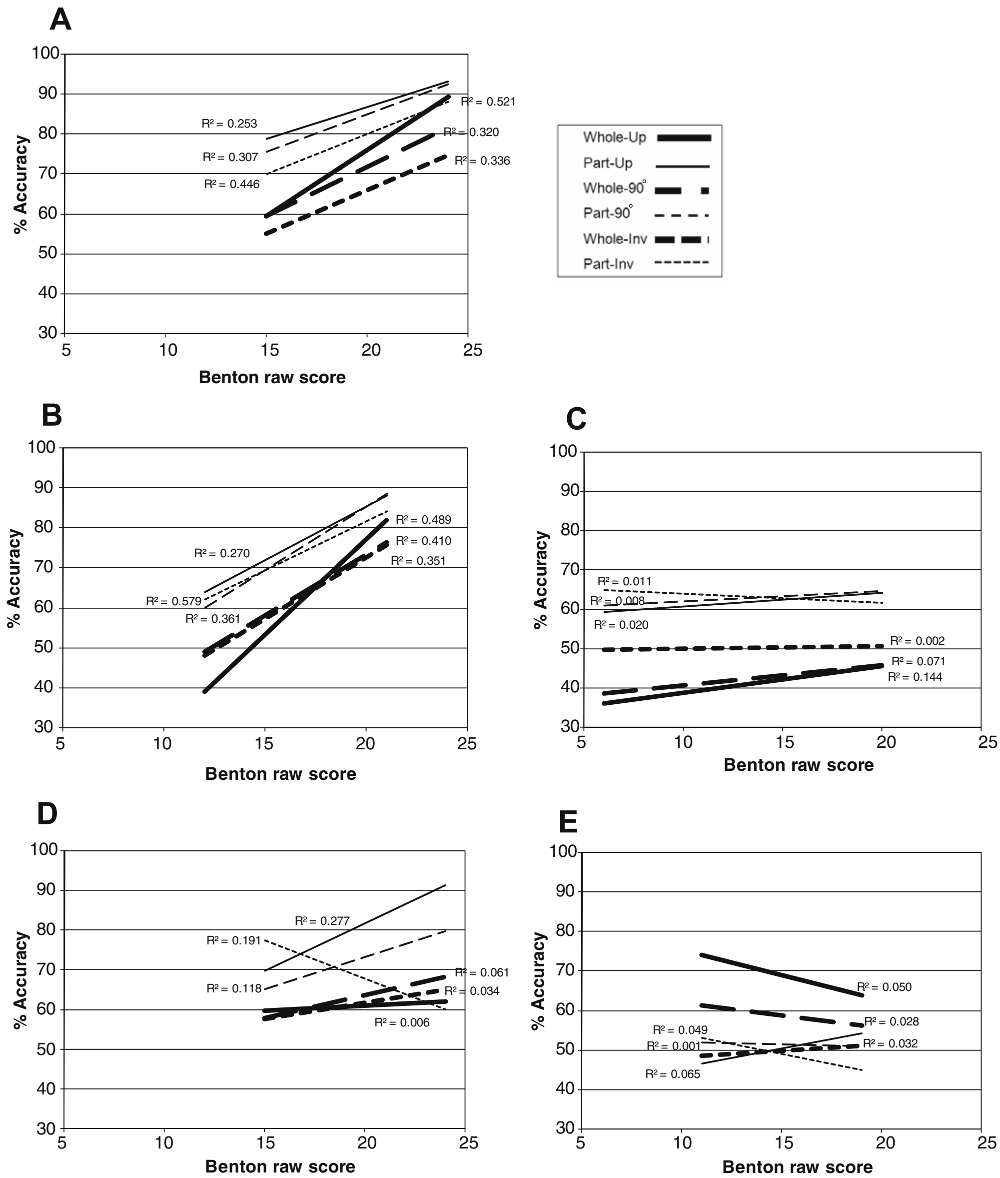

Fig. 5. Trajectories for all groups when plotted against Benton raw score, a test of face recognition ability. (A) TD group. (B) HFA group. (C) LFA group. (D) WS group. (E) DS group. Inv, inverted.

by MA normalized the onset and rate of part–whole development for the HFA group but did not reinstate the absent inversion effect.

Low-functioning autism. The main outcomes for the LFA group were a reliable improvement with CA, an advantage for part-face discrimination, and a reverse inversion effect driven by superior discrimination of inverted stimuli in the whole-face condition. Although onset was delayed compared with the TD group, the rate of development was comparable. BPVS predicted performance marginally more powerfully than did CA, $F(1, 15) = 5.72$, $p = .030$, $\eta_p^2 = .276$. Main effects of part–whole and orientation, as well as the interaction of these two factors, are purely repeated-measures effects and so are unchanged by replacing the predictor (see note 1). Plotting performance according to BPVS did not alleviate the delayed onset compared with the TD group, and the reverse inversion effect remained reliable (group by orientation interaction: $F(1, 38) = 8.95$, $p = .005$, $\eta_p^2 = .191$). Neither PC nor the Benton test proved to be a reliable predictor of part–whole performance in the LFA group (PC: $F(1, 15) = 3.52$, $p = .080$, $\eta_p^2 = .190$; Benton: $F(1, 15) = 0.61$, $p = .449$, $\eta_p^2 = .039$), and neither alleviated the delay in onset compared with the TD group (group effect—PC: $F(1, 38) = 23.55$, $p < .001$, $\eta_p^2 = .383$; Benton: $F(1, 38) = 22.77$, $p < .001$, $\eta_p^2 = .375$). However, in both of these analyses, there was a reliable group by mental age interaction (PC: $F(1, 38) = 8.96$, $p = .005$, $\eta_p^2 = .191$; Benton: $F(1, 38) = 13.00$, $p = .001$, $\eta_p^2 = .255$). That is, although part–whole performance was developing at a rate commensurate with these children's level of receptive vocabulary, it was developing more slowly than one would expect for their level of both pattern construction and face recognition ability. Lastly, the reverse inversion effect persisted for the PC and Benton trajectories (PC: $F(1, 38) = 4.26$, $p = .046$, $\eta_p^2 = .101$; Benton: $F(1, 38) = 12.87$, $p = .001$, $\eta_p^2 = .253$). In sum, MA trajectories did not change the principal anomaly in the LFA group or the reverse inversion effect, and they did not alleviate the delay in onset. This delay aside, performance improved in line with BPVS but more slowly than expected for PC and Benton MAs.

Williams syndrome. The principal features of the CA trajectory for the WS group were a slower rate of development compared with the TD group but no delay in onset and, strikingly, an inversion effect that emerged for part-face discrimination instead of whole-face discrimination in the TD group. CA did not predict performance on the task as a main effect across all conditions, nor indeed did any MA measure (BPVS: $F(1, 13) = 2.61$, $p = .130$, $\eta_p^2 = .167$; PC: $F(1, 13) = 0.01$, $p = .932$, $\eta_p^2 = .001$; Benton: $F(1, 13) = 0.99$, $p = .339$, $\eta_p^2 = .070$). There was an indication that when performance was plotted by PC MA, the onset in WS performance was higher than that of controls, $F(1, 36) = 3.84$, $p = .058$, $\eta_p^2 = .096$. It should be noted that visuospatial cognition tapped by PC is a relative weakness in the disorder, and face-processing skills are in advance of this measure. Trajectories constructed according to PC MA were greatly truncated, reducing the opportunity to predict variance in performance from this measure. All MA measures rendered the group by MA interaction nonsignificant when the WS group was compared with the TD group, implying that the rate of improvement on part–whole was in line with MA. Importantly, the emergence of the inversion effect for parts instead of wholes remained in the trajectories of all MA measures (group by part–whole by orientation by MA interaction—BPVS: $F(1, 36) = 5.12$, $p = .030$, $\eta_p^2 = .124$; PC: $F(1, 36) = 14.63$, $p = .001$, $\eta_p^2 = .289$; Benton: $F(1, 36) = 11.65$, $p = .002$, $\eta_p^2 = .245$). Constructing the trajectories by MA eliminated the delay in rate of development, indicating that performance on the part–whole task developed in line with measures of MA. However, the principal atypicality, an emerging orientation effect for parts instead of whole faces, remained present in the MA trajectories.

Down syndrome. The main features of the CA trajectory for the DS group were superior performance on the whole-face condition over the part-face condition (the opposite effect to all other groups), part–whole performance that was delayed in its onset and with a slower rate of development compared with the TD group, and performance that did not reliably increase with age. Finally, rotation produced a complex pattern, with a consistent effect on whole faces but a pattern that changed with age on part faces. The DS group was poor on both BPVS and PC, effectively truncating their developmental trajectories at a low age for these MA measures. This reduces the opportunity to predict variance in performance from these measures. None of the three MA measures reliably predicted performance across age (BPVS: $F(1, 13) = 0.10$, $p = .761$, $\eta_p^2 = .007$; PC: $F(1, 13) = 2.12$, $p = .169$, $\eta_p^2 = .140$; Benton: $F(1, 13) = 0.25$, $p = .625$, $\eta_p^2 = .019$). The onset of development was still delayed under all three measures (BPVS: $F(1, 36) = 6.90$, $p = .013$, $\eta_p^2 = .161$; PC: $F(1, 36) = 5.53$, $p = .024$, $\eta_p^2 = .133$; Benton: $F(1, 36) = 18.13$, $p < .001$, $\eta_p^2 = .335$). The interaction of part–whole with group remained for all three MA measures (BPVS: $F(1, 36) = 26.06$, $p < .001$, $\eta_p^2 = .420$; PC: $F(1, 36) = 24.09$, $p < .001$, $\eta_p^2 = .401$; Benton: $F(1, 36) = 32.42$, $p < .001$, $\eta_p^2 = .474$), and so did the complex inversion pattern shown by the DS group compared with the TD group (BPVS: $F(1, 36) = 7.27$, $p = .011$, $\eta_p^2 = .168$; PC: $F(1, 36) = 4.00$, $p = .053$, $\eta_p^2 = .100$; Benton: $F(1, 36) = 6.05$, $p = .019$, $\eta_p^2 = .144$). In short, constructing the trajectories by MA eliminated none of the atypical patterns for the DS group; the delay in onset remained, as did the reverse part–whole effect and the complex inversion pattern.

Feature-specific effects. Table 2 illustrates the accuracy levels for each group split by the individual features of eyes, nose, and mouth. Data are also split by part–whole condition and orientation for each group. The main effects of feature did not interact with CA or any MA measure for any participant group, and so the following analyses are collapsed over age. Most of the groups showed a prototypical pattern of optimal performance on discrimination of eyes, followed by mouths, with worst performance on noses (e.g., TD: main effect of feature, $F(1, 24) = 103.67$, $p < .001$, $\eta_p^2 = .812$). The difference between the features was more marked in the whole-face condition than in the part-face condition, although this difference emerged only as a trend in the TD group, $F(1, 24) = 3.68$, $p = .067$, $\eta_p^2 = .133$, and the feature effect was weakened by inversion, $F(1, 24) = 4.87$, $p = .037$, $\eta_p^2 = .169$. Part–whole and rotation effects were additive.

Only two disorder groups showed any particular variation from this prototypical pattern. First, the WS group found mouths harder to discriminate than other groups and, indeed, harder than noses in upright faces (TD vs. WS, group by feature interaction: $F(1, 38) = 15.44$, $p < .001$, $\eta_p^2 = .289$). Second, the LFA group performed comparatively better on mouths and comparatively worse on eyes than did other groups (TD vs. LFA, group by feature interaction: $F(1, 40) = 12.49$, $p = .001$, $\eta_p^2 = .274$). The LFA group's pattern of performance across features was also less modulated by inversion (group by feature by orientation interaction: $F(1, 40) = 7.59$, $p = .009$, $\eta_p^2 = .159$).

Joseph and Tanaka (2003) reported feature-specific effects when they used the original part–whole paradigm with high-functioning children with autism. In particular, for the whole-face condition, they reported an inversion effect for mouths ($p = .002$) but not for eyes ($p = .693$) (results for the nose feature were removed from the original analysis). An MA-matched mixed disability group with no autistic symptoms but a "history of language difficulties and/or delay" (p. 536) demonstrated inversion effects for both eyes ($p = .003$) and mouths in the whole-face condition ($p = .020$), leading to a group by orientation by feature interaction ($p = .007$).

We compared these effects with our results for the TD, HFA, and LFA groups using the three levels of rotation in the whole-face condition. All three groups showed reliable rotation effects for the eye feature. This was strongest for the TD group, $F(1, 24) = 39.20$, $p < .001$, $\eta_p^2 = .620$, significantly weaker for the HFA group (orientation: $F(1, 15) = 4.31$, $p = .055$, $\eta_p^2 = .223$; orientation by group interaction: $F(1, 39) = 12.70$, $p = .001$, $\eta_p^2 = .246$), and in a reverse direction for the LFA group; that is, inverted stimuli were responded to more accurately (orientation: $F(1, 16) = 8.20$, $p = .011$, $\eta_p^2 = .339$; LFA vs.

Table 2
Overall group accuracy levels (%) by feature on the part–whole task (SD, standard deviation). TD*, subset of the TD group approximately matched on CA to the disorder groups ($n = 18$).

		Whole						Part					
		Eyes		Nose		Mouth		Eyes		Nose		Mouth	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group													
TD	Upright	90	14	55	20	75	23	93	10	77	17	85	12
TD*		94	8	61	18	84	17	95	8	81	15	88	10
HFA		75	17	54	23	70	25	84	22	61	21	88	14
LFA		32	14	36	12	54	16	46	20	59	13	77	18
DS		92	18	52	18	68	12	62	15	38	13	47	17
WS		81	24	66	17	51	17	71	16	78	22	69	19
TD	90°	75	16	59	20	73	22	86	17	73	19	89	16
TD*		80	13	64	21	81	20	90	14	77	18	94	10
HFA		77	17	55	18	68	18	83	24	67	17	85	17
LFA		30	11	38	15	58	12	53	28	59	10	76	15
DS		63	11	53	17	62	13	67	14	41	17	47	18
WS		77	18	60	15	60	22	73	16	70	19	76	17
TD	Inverted	67	18	51	16	74	19	83	12	71	19	80	14
TD*		72	14	55	14	81	14	88	10	77	14	81	14
HFA		70	14	56	29	72	16	79	18	65	15	85	13
LFA		43	8	46	14	61	12	61	13	55	15	74	16
DS		52	11	46	13	50	13	60	20	40	20	51	20
WS		73	15	61	16	56	22	64	17	54	28	69	20

TD: $F(1, 40) = 38.65$, $p < .001$, $\eta_p^2 = .491$). The rotation effect for eyes differed reliably between the two autistic groups, $F(1, 31) = 12.18$, $p = .001$, $\eta_p^2 = .282$.

There were no reliable effects of orientation on the mouth feature when presented in the context of a whole face (TD: $F(1, 24) = 0.03$, $p = .866$, $\eta_p^2 = .001$; HFA: $F(1, 15) = 0.36$, $p = .701$, $\eta_p^2 = .023$; LFA: $F(1, 16) = 2.86$, $p = .110$, $\eta_p^2 = .152$). Similarly, for the nose feature, neither the TD group nor the HFA group indicated an effect of rotation (TD: $F(1, 24) = 1.06$, $p = .313$, $\eta_p^2 = .042$; HFA: $F(1, 15) = 0.05$, $p = .820$, $\eta_p^2 = .004$). However, notably, the LFA group once again exhibited a reverse inversion effect, with performance more accurate on inverted noses, $F(1, 16) = 11.59$, $p = .004$, $\eta_p^2 = .420$. The LFA pattern differed reliably from TD but not from HFA (LFA vs. TD: $F(1, 40) = 6.83$, $p = .013$, $\eta_p^2 = .146$; LFA vs. HFA: $F(1, 31) = 0.70$, $p = .408$, $\eta_p^2 = .022$).

In sum, our results were similar to those of Joseph and Tanaka (2003) in the weakened inversion effect for eyes presented in whole faces in the HFA group. In addition, we demonstrated a reverse inversion effect for the LFA group. Mouths showed no effect of orientation, but notably the LFA group showed a reverse inversion effect for noses presented in whole faces. This implies that feature-specific effects in autism are not restricted to just eyes and mouths.

Response time data

For reasons of space, our discussion of the response time (RT) data is briefer. These data were somewhat noisier than the accuracy data. A median RT was computed for each participant in each condition. Table 3 shows the RTs and accuracy levels for each group, split by part–whole condition. For the TD, HFA, and LFA groups, greater accuracy in the part condition was accompanied by faster responses. For the WS group, the RT difference was nonsignificant. For the DS group, accuracy was greater in the whole condition, whereas RTs did not significantly differ across the conditions. In the Discussion, we return to the relevance of these results for the possible strategies adopted by each group.

Trajectory analyses evaluated the extent to which age predicted RTs, with both variables log-transformed to improve the linearity of the data. In the TD group, RTs became reliably faster with age, $F(1, 23) = 25.80$, $p < .001$, $\eta_p^2 = .529$, upright stimuli were responded to more quickly than were rotated stimuli, $F(1, 24) = 7.91$, $p = .010$, $\eta_p^2 = .248$, and there was a trend for stimuli in the part-face condition to be discriminated more quickly than stimuli in the whole-face condition, $F(1, 24) = 3.77$, $p = .064$, $\eta_p^2 = .136$. These results are all broadly in line with the accuracy results, although no interactions were detected in the RT data (e.g., the part–whole by orientation by CA interaction observed in the accuracy analysis). For the disorder groups, neither CA nor MA reliably predicted RTs for any group, and CA appeared in only two reliable interactions. The HFA group showed faster performance on the part condition than on the whole condition, in line with the TD group, $F(1, 15) = 16.85$, $p = .001$, $\eta_p^2 = .529$. The LFA group also was faster on the part condition, $F(1, 16) = 19.48$, $p < .001$, $\eta_p^2 = .549$, but showed an effect of orientation. The LFA group was faster on inverted stimuli,

Table 3
Mean reaction times and accuracy levels for each participant group for whole and part trials. *p* values are for paired *t* tests.

		Whole		Part		p value
		Mean	SD	Mean	SD	
Group						
TD	RT (s)	4.9	1.6	4.6	1.9	.159
	Accuracy (%)	69	15	82	11	< .001
TD*	RT (s)	4.6	1.5	4.1	1.6	.046
	Accuracy (%)	75	11	86	9	< .001
HFA	RT (s)	4.5	0.7	3.7	0.7	.001
	Accuracy (%)	67	15	78	12	.001
LFA	RT (s)	4.6	0.7	3.5	0.7	< .001
	Accuracy (%)	46	7	64	11	< .001
DS	RT (s)	5.9	1.3	5.8	1.4	.676
	Accuracy (%)	60	13	50	8	< .001
WS	RT (s)	4.6	1.0	4.4	0.7	.438
	Accuracy (%)	62	10	74	12	<.001

$F(1, 16) = 22.41$, $p < .001$, $\eta_p^2 = .583$, again in line with the group's accuracy results, and this effect became stronger with age (orientation by CA interaction: $F(1, 15) = 12.45$, $p = .003$, $\eta_p^2 = .454$). The WS group appeared to become faster with age on the part-face condition but slower with age on the whole-face condition (part–whole by CA interaction: $F(1, 16) = 7.80$, $p = .015$, $\eta_p^2 = .375$), consistent with the idea that upright part-face/feature recognition is particularly exploited by this group. Finally, the DS group was faster on upright stimuli but showed no other effects, $F(1, 14) = 7.52$, $p = .016$, $\eta_p^2 = .350$. Direct comparisons of the TD and disorder groups tended to mask group-specific effects due to the large amount of variability in the combined analyses.

Discussion

In comparison with previous use of the part–whole task, the most notable finding for our typically developing children was a reverse pattern of difficulty compared with Tanaka and Farah's (1993) results. In our version of the task, matching of face feature to target was easier in the part condition than in the whole condition, whereas Farah and Tanaka found that recall was easier in the whole condition than in the part condition. In our results, a consistent pattern of RT data indicated that the direction of the difference was not a speed–accuracy trade-off. What is the possible source of this reverse effect? The two versions of the part–whole task differed in three ways. First, they used different stimuli. Second, we included an additional orientation to tap rotation effects (90°). Third, we omitted the memory component from the task where participants needed to first learn the target faces in a training phase; in our task, the target face was presented simultaneously with the two response stimuli.

The memory component is most likely to explain the opposite direction of the part–whole effect. In Tanaka and Farah's (1993) paradigm, participants first memorize faces and then the task involves retrieval of the target face given the cue of either the whole face or a feature from that face. Because the whole face is more similar to the encoded face than is an isolated feature, the whole face condition is likely to produce better retrieval (i.e., context at retrieval is most similar to context at encoding). In our version, the task involves a direct comparison of two alternative stimuli against the target face, where one stimulus differs in a single feature. Identifying this feature is likely to be slowed if the individual feature is fused with the whole face (i.e., engages holistic processing). Therefore, the isolated feature allows easier comparison. In this way, our version of the task has more in common with the composite face paradigm, in which the two halves of a face are harder to identify separately when they fuse into a whole. In principle, this interpretation of the difference is testable by repeating Tanaka and Farah's paradigm but varying the memorization phase to include either parts of faces or whole faces. However, for the concerns of the current study, it is not clear whether reversing the direction of the part–whole effect is a crucial difference; if the context in which a face feature is processed modulates recognition, presumably we are still tapping holistic processing (see Leder & Carbon, 2005, for a discussion of the conditions under which context helps or hinders face recognition; see Koshino et al., 2008, for a discussion of working memory and face recognition).

In our TD group, the part–whole difference was present from the youngest child tested. The respective developmental trajectories were already nonoverlapping from 2 years 9 months onward, and the size of the part–whole effect did not change significantly across age. However, performance on the task did increase with age, and RTs decreased. Rotation impaired performance, but the rotation effect emerged with age only for whole faces, whereas it was constant across age for isolated features. This is consistent with the emergence of a specialized template-matching process for recognizing upright faces (Tanaka & Farah, 1993; see Diamond & Carey, 1986, for norm-based accounts; see Tanaka & Farah, 1993, and Tanaka & Sengco, 1997, for discussions of accounts based on the accessibility of different types of facial information). However, the data must be interpreted with some caution because an attenuated rotation effect for whole faces might be the result of floor performance in the youngest children, and it is weaker if only older children are considered. What explains the improvement in overall performance if the part–whole effect is constant? There are at least two possibilities. First, if the emerging rotation effect for whole faces is real, the task improvement across age may reflect the development of a specialized process for recognizing whole upright faces. This would imply that the part–whole manipulation and rotation manipulation are not strictly measuring the development of the same process. We return to this point later. Second, the improvement in task performance with age may be related to other cognitive factors (e.g., attention, speed of processing, working memory capacity). These possibilities are not mutually exclusive (e.g., Koshino et al., 2008; Mervis et al., 2000).

We now consider how the typical pattern of development was modulated by each disorder. First, let us consider autism. In the Introduction, we discussed research suggesting that perceptual processing in general, and face recognition in particular, may be featural in character, where perhaps this characteristic of processing is at odds with holistic processing. Tentatively, based on previous literature, we predicted a reduced inversion effect and the possibility of feature-specific effects. Our data indicated that for high-functioning children with autism, the part–whole effect was normal. To the extent that this manipulation taps holistic recognition, this process had developed normally by the age when we began constructing the cross-sectional developmental trajectory. Nonetheless, there were some differences. For the HFA group, the level of performance was in line with MA measures rather than CA measures. Most salient, performance did not decrease reliably when the presentation of the stimuli was rotated. This supports the idea that part–whole effects and rotation effects can dissociate and that the featural nature of HFA processing pertains to rotation but not part–whole. When trajectories were constructed according to performance on the Benton test, the absence of the inversion effect compared with TD children was particularly evident. That is, a similar level of face recognition (on the Benton test) could be delivered by a system that is insensitive to the orientation of faces on the part–whole task. The implication is that in this disorder there is no specialized template for the recognition of upright faces. The system is sufficient for face discrimination using features that are not disrupted by inversion, delivering performance scores in line with CA. As discussed in the Introduction, one view is that inverted faces may be recognized by the object recognition system in the normal case (e.g., Epstein, Higgins, Parker, Aguirre, & Cooperman, 2006; Yovel & Kanwisher, 2005). In the HFA group, then, it may be the case that both upright and inverted faces are recognized in this way, leading to insensitivity to inversion. If the object recognition system has greater feature-based sensitivity than normal, it may be able to support an adequate level of the within-category discrimination that is required for face recognition.

Uncommon to most studies, we also examined the performance of low-functioning children with autism, as assessed by severity of clinical symptoms. How does the spectrum affect face recognition? The level of performance was lower than expected for CA or any MA measure, but it then increased at a rate commensurate with CA and vocabulary ability. However, it improved more slowly than expected given visuospatial constructive skills (a strength for these children) and the Benton test. Whereas the HFA group demonstrated no inversion effect, the LFA group exhibited a reverse inversion effect, with performance being more accurate on inverted stimuli. This stemmed from a particular disadvantage in discriminating features in whole upright faces. Lastly, the LFA group demonstrated additional feature-specific effects, including a disadvantage for discrimination based on eyes and an advantage for discrimination based on mouths. We also found that eyes were discriminated better in inverted faces, whereas for mouths the orientation did not matter. Interestingly, noses (not reported by Joseph & Tanaka, 2003) also indicated better discrimination when occurring in inverted faces.

One interpretation is that these children had an aversion to looking at eyes in upright faces and did not like to look at noses in upright faces simply because they were too close to the eyes. Mouths were far enough away from the eyes to be discriminated in upright faces while not fixating near the eyes and so did not show the reverse inversion effect. The LFA pattern, therefore, might not reflect the characteristics of face recognition processes per se; rather, it might reflect the operation of a motivation system with reward values for fixating or not fixating particular parts of faces (Klin et al., 2002; Langdell, 1978; Mundy & Burnette, 2005; see Triesch, Teuscher, Deak, & Carlson, 2006, for a computational model of the anomalous development of eye gaze following in autism using a reward-based learning system). The adequacy of face recognition for children who are at the severe level on the autistic spectrum, then, has two atypical characteristics: poor recognition performance overall and deliberate avoidance of the eyes in upright faces. If eyes are crucial for face recognition, this alone may explain the poor performance. That said, if we take the part–whole manipulation to tap the existence of holistic processing in the LFA group, we must also conclude that holistic processing is present from the earliest age measured, is constant across age, and is indistinguishable in nature from that observed in the TD group.

Individuals with *Williams syndrome* are noted for their relatively strong face recognition abilities. Indeed, of the disorder groups, these children were alone in performing at the level of the TD group on the Benton test. However, this achievement does not guarantee normal underlying processes (Karmiloff-Smith et al., 2004; Mills et al., 2000; Tsirempolou, Lawrence, Lee, Ewing, & Karmiloff-Smith, 2006), and the existing literature led us to predict a reduced inversion effect based on a featural style of processing. Indeed, the part–whole task did reveal an anomalous pattern. Although overall performance was in line with MA, the WS group did not show an emerging inversion effect for whole faces. But this group did show an *emerging inversion effect for part-face discrimination*. What are we to infer from this? For the TD group, emerging inversion effects for whole faces are generally taken to index the development of some specialized process or strategy for recognizing upright faces (e.g., Rakover, 2002). This logic suggests that we should interpret the WS accuracy data to indicate the emergence of a specialized process for recognizing *parts of faces* rather than whole faces. The RT data support this; indeed, the WS group became faster with age on part-face discrimination but slower with age on whole-face discrimination. This pattern was not observed in the other clinical groups.

In the Introduction, we noted that both the WS and HFA groups have been characterized as exhibiting featural processing in face recognition and other cognitive domains. A direct comparison demonstrated that this common label is too vague because the disorders clearly differed on the *part–whole* task. As with TD children, both groups found part-face discrimination to be easier than whole-face discrimination, implying the presence of holistic processing. But the HFA group showed no inversion effect at all, and the WS group showed an emerging inversion effect on features only. Moreover, based on CA, the WS strategy was more effective. One possible interpretation to reconcile these data is that the HFA processing is even more featural. In the WS group, processing is featural only at the level of face features (e.g., eyes, nose, mouth), whereas in the HFA group, the visual detail used to drive recognition is more fine-grained. This interpretation is consistent with differences observed in electrophysiological measures of brain function during face recognition. Grice and colleagues (2001), Grice and colleagues (2003) noted different patterns of gamma bursts (i.e., voltage power at 40-Hz frequencies of oscillation) in adolescents and adults with WS and autism. According to the authors, this reflected differences in visual feature binding. Specifically, binding in (high-functioning) adults with autism looked very similar to that in controls except that changing the orientation of the stimulus failed to produce the normal pattern of modulation. In adults with WS, binding appeared to be anomalous, raising the possibility that differences in the relevant neuroanatomical substrate disrupt the basic neural processes of binding (see Eckert et al., 2005; Eckert et al., 2006). Under this view, a specialized whole-face template cannot emerge in WS, but the limitations nevertheless enable smaller scale templates to emerge for particular facial features.

Relatively little research has been carried out on face recognition in *Down syndrome* (Williams et al., 2005; Wishart & Pitcairn, 2000; Wishart et al., 2007). On the basis of existing data, it has been claimed that individuals with DS exhibit a global style in visuospatial processing (e.g., Bellugi et al., 1999), which one may take to be synonymous with visual processing that is more holistic and less featural. Therefore, we predicted that this might give rise to an increase in the size of the holistic effect. Surprisingly, the face recognition skills of the children with DS, as assessed by the Benton test, were as poor as those of the LFA group. Moreover, the DS group demonstrated the most anomalous pattern on the part–whole task. These children discriminated features better when presented in whole faces than when presented in isolation, unlike any other tested group. How can we explain this? One might indeed take this as evidence that there is an emphasis on holistic processing in these children. But note that if this were the sort of holistic processing present in the TD group, it would have disadvantaged performance on whole-face stimuli rather than aided it. We suggest here that the DS system is actually poor at processing features. These children need the context of a whole face to help them recognize features in the first place. In the other groups, features are recognized adequately, and holistic processing then compromises discriminability by fusing them with the whole-face context. The global style in DS, then, would be an index of the poor processing of local elements (Bihrle et al., 1989).

According to the Benton test, the DS and LFA groups were equally poor at face recognition. Were they poor in a similar way? A direct comparison of the groups on the part-whole task reveals that they were not. Children with DS performed best on upright whole faces, the very condition on which the LFA group performed worst. We have argued that this is because children with DS need the context of an upright face to support the recognition of facial features, whereas the LFA group seeks to avoid processing eyes in upright faces because these children find eyes to be aversive.

To what extent might the profiles of each group fit within an expertise account of face recognition (Bukach et al., 2006)? Differences in the level of social engagement observed in WS and autism might fit within this account. In WS, there is elevated social engagement and a particular fascination with faces. Autism, in contrast, is characterized by social disengagement, and children may avoid looking at faces (and particularly at eyes). In WS, more practice on recognizing faces may allow the development of performance levels within the normal range (as indicated on the Benton test) via a system that operates using a different set of constraints such as reliance on part-face processing. In autism, part of the profile of performance may simply reflect lack of practise in recognizing faces, particularly in the LFA group. Nevertheless, performance in the HFA group indicates that even when clinical symptoms were not especially marked, anomalies in the inversion effect were still present, suggesting atypical perceptual processes despite (presumably) a more normal level of practice on recognizing faces.

To what extent might the pattern of results reflect specifics of the task design and the way in which children with different levels of intellectual disability attempted to solve the part–whole task? It is certainly true that one must carefully consider the details of the holistic paradigm that has been chosen (Richler, Gauthier, Wenger, & Palmeri, 2008). Lopez and colleagues (2004) demonstrated that the use of an attentional cue pointing to particular face features could influence performance, suggesting that individual differences in attention might modulate behavior. What task effects could differ across groups and thereby offer potential explanations of our results? During testing, we did not observe any obvious differences in strategies across groups. The RTs on the task were on the order of 5 s, permitting the participants to look back and forth between the target and comparison stimuli. Table 3 indicates no strong evidence of different speed–accuracy trade-offs across groups, with the poorest performing groups responding the slowest. One reviewer suggested that the DS group perhaps did not pick up on a particular strategy of feature matching that the other groups employed due to the lower level of general intellectual disability in DS. This is a possibility, and the part–whole paradigm could certainly be complemented by eye tracking to explore matching strategies in greater detail.

However, we are wary of viewing general intellectual disability as the sole explanation of group differences because (a) the cognitive profiles of these developmental disorders are uneven, meaning that the apparent level of disability for a group depends on the choice of measure; (b) different part–whole response patterns were exhibited by children in groups that nevertheless exhibited similar levels of overall task performance (e.g., WS vs. HFA, DS vs. LFA); (c) children in the LFA group, whose poor performance on the part–whole task might be attributable to intellectual disability, were nevertheless able to score within the normal range for their CA on pattern construction, a visuospatial constructive task involving comparison of a whole target pattern with a constructed pattern made up of parts.

We have considered the performance of four disorder groups on the part–whole task and found that every disorder group was atypical in a different way. What can we learn about typical development from the possible ways in which face recognition (and the contribution of holistic processing) can vary in the disorders? The following paragraphs suggest a tentative proposal.

1. Holistic processing is an early appearing and robust aspect of face recognition. By the term *holistic processing*, we mean a gestalt process of fusion between different visual elements in an array, probably carried out in low-level vision by lateral processes of excitation and inhibition. It is this process that is tapped by the part–whole manipulation. We did not detect any development of this process across our age ranges.

2. The role of holistic processing may be advantageous or disadvantageous depending on the task, specifically whether it is important to preserve the independent identity of elements in a visual array. Memory processes may alter the task characteristics (e.g., performance may be optimized when context at retrieval is the same as context at encoding). A feature memorized in a face will be recognized best in a face.
3. The emerging inversion effects, for the whole-face condition in the TD group and the part-face condition in the WS group, suggest that something else is developing. We believe that this is a template-matching process, specialized for the level of the granularity being employed to drive recognition (upright whole faces for the TD group and upright face features for the WS group). The template-matching process is not the same thing as the gestalt fusion process. It is tapped by the manipulation of stimulus orientation and develops across the age range in some, but not all, of the populations. For this account to work, one would need a separate explanation of apparent inversion effects in face processing observed in infants using the habituation paradigm (Cohen & Cashon, 2001), perhaps related to changes in the acuity of perceptual encoding (Thomas, 2004).
4. Inversion effects can be absent while part–whole effects are still present, as in the HFA group. This supports the view that the two manipulations tap processes whose developmental trajectories may differ. Face recognition must also be viable via processes that do not invoke template matching, perhaps by a process that operates at a finer grain of visual detail than normal.
5. It is necessary to have good recognition of features before the pros and cons of fusing features become relevant. In DS, familiar whole-face upright contexts may be necessary to support the recognition of features.
6. External factors may modulate the development of face recognition. In the LFA group, eyes in upright faces appear to be an aversive stimulus. In such cases, other visual information may be exploited for face recognition but may be less efficient, leading to lower overall performance. In WS, even in the presence of atypical constraints, a greater level of practice in recognizing faces may bring performance within the normal range on the same tasks.

We have omitted from this sketch another aspect of face recognition, namely, the computation of configurations between face features (Mondloch et al., 2002). Holistic face processing and configural face processing are clearly related in that they are both involved in the recognition of upright whole faces. However, the developmental time courses of the two processes appear to be different. Configural processing is a later developing marker of expertise in face recognition and may index the requirement of the system to discriminate more faces than is possible using the template-matching procedure implicated in holistic processing. Our current work is extending the cross-syndrome trajectory analysis approach to investigate the development of configural processing in face recognition.

Normal development is a process that operates under constraints. Developmental disorders throw these constraints into relief when the constraints vary. Perhaps the most striking result of the current study is the different impact that atypical developmental constraints have on the efficiency of face recognition, as exhibited by performance on the Benton test. In some cases the impact is severe, whereas in others it is not. Viewed in isolation, results from the Benton test would tell us that WS face recognition is normal, that HFA face recognition is not far from normal, and that the LFA and DS groups are similar in their low performance. The results of the part–whole task demonstrate that all of these disorders have different atypical constraints.

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Appendix A. Table A

CARS scores for HFA and LFA groups

HFA			LFA		
Participant number	CARS score	BPVS standard score	Participant number	CARS score	BPVS standard score
1	32	92	1	38	84
2	31	70	2	39	44
3	30	62	3	55	46
4	30	87	4	47	44
5	31	94	5	56	49
6	34	80	6	48	51
7	32	77	7	49	46
8	32	112	8	52	55
9	33	89	9	48	65
10	35	96	10	43	65
11	35	92	11	51	70
12	36	88	12	49	74
13	34	95	13	43	65
14	35	91	14	49	111
15	32	93	15	41	109
16	33	93	16	55	84
			17	47	87
Mean	33	88		48	67
SD	2	11		5	26
Minimum	30	65		38	44
Maximum	36	112		56	111

Note. The higher the rating, the more severe the autistic symptoms. Standard scores on the BPVS-II for receptive vocabulary skills are also shown.

Appendix B. Table B

Frequency distribution of ages for each participant group split according to CA and three standardized measures: BPVS, PC test, and Benton test

	TD	HFA	LFA	WS	DS
CA					
2 years 9 months–4 years 11 months	6				
5 years 0 months–6 years 11 months	6	4	3	3	3
7 years 0 months–8 years 11 months	6	6	7	5	3
9 years 0 months–10 years 11 months	4	5	5	5	5
11 years 0 months–13 years 1 month	3	1	2	2	4
BPVS					
2 years 9 months–4 years 11 months	5	1	14	2	14
5 years 0 months–6 years 11 months	6	9		6	1
7 years 0 months–8 years 11 months	5	4	3	6	
9 years 0 months–10 years 11 months	6	2		1	

Table B (*continued*)

	TD	HFA	LFA	WS	DS
11 years 0 months–12 years 11 months	3				
PC					
2 years 9 months–4 years 11 months	5	3	2	14	15
5 years 0 months–6 years 11 months	5	3	4	1	
7 years 0 months–8 years 11 months	7	5	5		
9 years 0 months–10 years 11 months	6	3	4		
11 years 0 months–12 years 11 months	2	1	1		
Benton raw score					
5–10			3		
10–15	5	4	9	1	13
15–20	11	10	5	9	2
20–25	9	2		5	

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