JIDR Journal of Intellectual Disability Research
Published on behalf of mencap and in association with IASSID

Journal of Intellectual Disability Research doi: 10.1111/jir.12141

Atypical development of configural face recognition in children with autism, Down syndrome and Williams syndrome

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Abstract

Background Configural processing in face recognition is a sensitivity to the spacing between facial features. It has been argued both that its presence represents a high level of expertise in face recognition, and also that it is a developmentally vulnerable process.
Method We report a cross-syndrome investigation of the development of configural face recognition in school-aged children with autism, Down syndrome and Williams syndrome compared with a typically developing comparison group. Cross-sectional trajectory analyses were used to compare configural and featural face recognition utilising the 'Jane faces' task. Trajectories were constructed linking featural and configural performance either to chronological age or to different measures of mental age (receptive vocabulary, visuospatial construction), as well as the Benton face recognition task.
Results An emergent inversion effect across age for detecting configural but not featural changes in faces was established as the marker of typical development. Children from clinical groups displayed atypical profiles that differed across all groups.
Conclusion We discuss the implications for the nature of face processing within the respective developmental disorders, and how the cross-sectional syndrome comparison informs the constraints that shape the typical development of face recognition.

Keywords autism, configural processing, Down syndrome, face recognition, inversion effect, Williams syndrome

Introduction

Faces have a special status as visual stimuli and the ability to recognise facial identity, emotion and direction of eye gaze provides vital information for social interaction. Faces attract the attention of adults in the environment (Hershler & Hochstein 2005), and an attention bias to faces is usually present from birth (Farroni *et al.* 2005). The status of face stimuli, however, may differ in some neurodevelopmental disorders, such as autism, Williams syndrome (WS) and Down syndrome

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(DS). While individuals with WS and DS show great interest in faces (e.g. Mervis *et al.* 2000), individuals with autism exhibit reduced looking times to people in social scenes (e.g. Klin *et al.* 2002; Annaz *et al.* 2010) and are less distracted by faces than typically developing children (Riby *et al.* 2012). These different patterns of face-related attention could result in divergent face processing abilities and strategies, with potential impact on social functioning. Hence in the current study, we examine *featural processing* which is driven by individual features such as the eyes, nose and mouth, and *configural processing* which is driven by the arrangement and spacing of these features in the face. Configural processing is disrupted by inversion effect while leaving featural processing relatively unimpaired (see Rakover 2002 for a review). In typical development (TD), the contribution of these processes to face recognition changes gradually with chronological age (CA), with configural processing being the last to appear (Maurer *et al.* 2002), emerging by 10 years of age (Mondloch *et al.* 2003; see also Freire & Lee 2001).

Autism spectrum disorder

Autism is a common neurodevelopmental syndrome characterised by clusters of difficulties in two domains, namely 'social communication and interaction' and 'restricted repetitive behaviour' (American Psychiatric Association, 2013). While there are marked differences in the extent and quality of the symptoms among individuals with autism, one of the most common features is a striking difficulty with social skills, including the ability to attend to and process faces (Klin *et al.* 2002).

A number of studies have reported that children with autism show greater attention to the mouth rather than to the eye region, compared with the typical pattern of a focus on the eye region (e.g. Annaz *et al.* 2009; Riby & Hancock 2009). It might be that this focus on the mouth represents a more featural processing strategy, whereas attending to the eye region promotes configural processing in order to assess the relative distance between the eyes, which may be a key factor in an accurate and fast face recognition (e.g. Leder & Bruce 2000). Studies of spatial frequency processing in face processing have suggested a reliance on high spatial frequencies (related to featural processing) in autism (Deruelle *et al.* 2008), although the differences between autism and TD groups may depend on the age at which participants are tested (Leonard *et al.* 2011).

Investigations of configural processing in adults with autism have yielded mixed results (Rutherford *et al.* 2007; Nishimura *et al.* 2008; Wallace *et al.* 2008). Specifically, using paradigms in which stimuli were presented simultaneously and for unlimited time, Nishimura *et al.* (2008) did not find performance differences between adults with autism and TD participants. In contrast, Rutherford *et al.* (2007) reported a deficit for adults with autism in perceiving differences in eye-to-eye spacing, but not mouth-to-nose spacing. An important point to note is that most of the preceding findings are based on studies of high-functioning individuals with autism or with Asperger syndrome. In the current study, we included low-functioning children with autism to explore individual variation in face recognition characteristics across the autism spectrum.

Williams syndrome (WS)

Williams syndrome is a rare genetic disorder caused by a hemizygous microdeletion of 28 genes on chromosome 7q11.23 (Tassabehji 2003), occurring in approximately 1 in 20 000 live births (Morris *et al.* 1988). It is characterised by an overall IQ between 55 and 69 (Mervis *et al.* 2000) and a 'hyper-social' personality profile.

Several studies have suggested that relatively good face recognition abilities in WS are achieved by atypical underlying processes, and in particular the preferential use of featural encoding, leading to a reduced inversion effect (Deruelle *et al.* 1999; Mills *et al.* 2000; Annaz *et al.* 2009). For instance, in their holistic face recognition study, Annaz *et al.* (2009) found that children in the WS group showed no inversion effect on the whole face trials but an emerging inversion effect on features. Furthermore, Leonard *et al.* (2011) found typical spatial frequency biases for face recognition in older children with WS, but different developmental pathways led to this outcome between WS and typical control groups. These atypical patterns may be due to unusual attention towards faces and scanning patterns of facial information (e.g. Riby & Hancock

2009; Riby *et al.* 2012). In particular, prolonged attention to faces, especially to the eye region, may produce different processing strategies to TD individuals (Riby & Hancock 2009). This atypical behavioural evidence is in line with a small number of imaging and Event related Potentials (ERP) studies indicating anomalous brain activation during face recognition (Mills *et al.* 2000; Grice *et al.* 2001). For example, Mills *et al.* (2000) found no difference in the brain response to upright and inverted faces in individuals with WS, while the control group activated two separate electrophysiological components in response to the two orientations. In an imaging study that contrasted WS with autism, Grice *et al.* (2001) observed differences in electroencephalographic gamma band oscillations between a WS group and both the autism and TD control groups. These authors argued that both WS and autism rely more on featural processing in face recognition but achieve a featural style of processing in different ways. The imaging data support the idea that individuals with autism and WS process faces differently at brain level, but we lack more detailed complementary behavioural studies that would directly compare the development of featural and configural processing in the two clinical groups.

Down syndrome (DS)

Down syndrome is the most common sporadic genetic disorder (1/700 live births) usually associated with the presence of three copies of chromosome 21 and an average IQ of around 50 points (Roizen & Patterson 2003).

Only a handful of studies have examined face processing in DS, and have mostly focused on emotion recognition. Annaz *et al.* (2009) reported atypical face recognition on a part–whole task in 15 children with DS. Unlike the other clinical groups tested (autism and WS), children with DS discriminated features better when presented in whole faces than when presented in isolation. The authors suggested that individuals with DS are poor at processing features and need the context of a whole face to support the recognition of individual features. Wishart & Pitcairn (2000) tested 16 children on identity and expression matching tasks. Their performance was compared with TD children matched on overall mental age (MA). Although children with DS were slower than the MA-matched group at identity-matching task, their accuracy was not significantly different from the controls. However, their performance was significantly poorer on the expression-matching task. Furthermore, unlike the TD group, children with DS were not sensitive to the orientation of the faces, which would imply weaker or absence of configural processing (see also Williams *et al.* 2005; Wishart *et al.* 2007). These studies suggest that although individuals with DS appear to have relatively good social skills, they do struggle with face recognition depending on context.

The current study

We adopted a cross-sectional, developmental trajectories approach to trace the emergence of configural and featural processing in autism, DS, WS and TD groups (see Annaz *et al.* 2008; Thomas *et al.* 2009 for analytical methods). Our key questions were whether face recognition developmental pathways are atypical in three clinical groups, whether deficits are similar or differ across them, and whether face recognition abilities are in line with scores on Benton Facial Recognition Test (Benton *et al.* 1983). Although the Benton test is often used in clinical settings, it should be noted that it has limitations as accurate performance can be achieved using feature-based strategies (Duchaine & Nakayama 2004). As development of face recognition skills is related to CA, we first examine groups' performance scores in relation to CA and then proceed to evaluate the role of MA in relation to face task performance.

Method

Participants

A total of 33 children with autism (28 male, 5 female; mean age = 8:6), 15 with DS (10 male, 5 female; mean age = 9:0), 18 with WS (8 male, 10 female; mean age = 8:6) and 25 TD comparison children (13 male, 12 female; mean age = 7:2) participated in our study (see Table 1 for group details. The TD sample had a greater age range in order to permit comparisons between disorder and TD trajectories either on the basis of CA or on the basis of MA, where disorder groups may have lower MAs.

Table 1 Test results per group

Group (sample size)	Statistic	CA (months)	Benton raw score	BPVS standard score (months)	PC standard score (months)
TD ($n = 25$)	Mean	86	19	91	91
	Std	33	3	31	31
	Min	33	15	39	43
	Max	149	24	154	147
HFA ($n = 16$)	Mean	101	18	83*	97
	Std	21	3	20	41
	Min	64	12	55	40
	Max	134	21	124	201
LFA ($n = 17$)	Mean	102	13*	54*	99
	Std	23	4	20	33
	Min	63	6	42	52
	Max	136	20	105	165
DS ($n = 15$)	Mean	108	14*	46*	38*
	Std	25	2	6	4
	Min	74	11	40	34
	Max	157	19	62	49
WS ($n = 18$)	Mean	102	20	78*	42*
	Std	25	2	23	10
	Min	68	15	38	34
	Max	145	24	124	64

* *t*-test significantly different from TD group $P < 0.05$.

TD: typically developing; HFA: high-functioning children with autism; LFA: low-functioning children with autism; DS: Down syndrome; WS: Williams syndrome; CA: chronological age; Benton score: raw score on Benton Face Recognition Test (Benton *et al.* 1983); BPVS: British Picture Vocabulary Scale (Dunn *et al.* 1997); PC: Pattern Construction subtest of the British Abilities Scale II (Elliot *et al.* 1997).

Children in the autism group met established criteria for autism, as specified in Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) (APA 2000) and Autism Diagnostic Observation Schedule (Lord *et al.* 1999), and all scored above cut-off for autism on the Childhood Autism Rating Scale (CARS) (Schopler *et al.* 1993). All children in the DS group had previously been tested positively for trisomy of chromosome 21. Children with WS had been diagnosed clinically as well as by means of the fluorescence *in situ* hybridisation test for microdeletion of specific gene markers.

Participants were recruited from London schools and, for the WS group, via the Williams Syndrome Foundation, UK. All individuals had normal or corrected-to-normal vision and children from the TD group had no previous or current learning problems or any other medical diagnosis.

Each child completed the British Picture Vocabulary Scale (BPVS) (Dunn *et al.* 1997) and the Pattern Construction (PC) test from the British Abilities Scale II (Elliot *et al.* 1997) in order to obtain verbal and visuospatial MA respectively. Face recognition skills were assessed on the Benton test (Benton *et al.* 1983) to evaluate whether this test predicted performance on the experimental task. Children in the autism group were assessed on the CARS (Schopler *et al.* 1993) to acquire their overall score on autism severity. As the distribution of scores was approximately bi-modal, children were divided into a low-functioning group (defined as CARS range 37–60 points: 15 male, 2 female; mean age = 8:6; henceforth referred to as the LFA group) and a high-functioning group (CARS range 30–36 points: 13 male, 3 female; mean age = 8:5; henceforth referred to as the HFA group).

Stimuli

We used the 'Jane' test developed by Mondloch *et al.* (2002) which has been used to study adults (Mondloch *et al.* 2010), TD children (Mondloch *et al.* 2002) and clinical populations such as individuals with developmental prosopagnosia

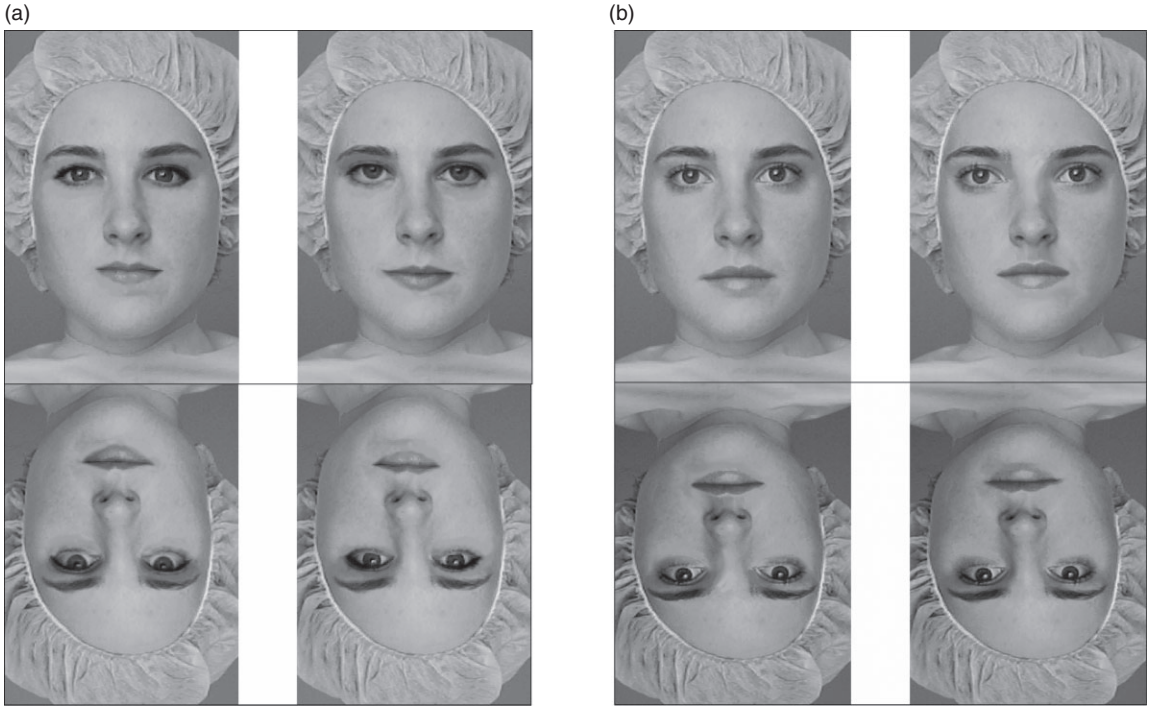

Figure 1 Example of the Jane faces stimuli (Mondloch *et al.* 2002). Panel a illustrates a sample of featurally altered faces in upright and inverted conditions. Panel b illustrates a sample of configurally altered faces in upright and inverted conditions. Reproduced with permission.

(Le Grand *et al.* 2006). Collectively, these studies provide a good picture of developmental processing of configural and featural face recognition.

The Jane test was developed using a black and white photograph of a woman (referred to as 'Jane') to create varied versions of the same face. The featural version was created by replacing the eyes or the mouth features of Jane's face with features of other people. In the configural version (referred to as the 'spacing set' by Mondloch *et al.* 2002), features such as the eyes were moved in either direction (horizontally or vertically) within the inner face; for example, the eyes were moved closer together by 4mm relative to the original. All stimuli were 10.2 cm wide and 15.2 cm high (Fig. 1). More detailed information about the stimuli can be found in Mondloch *et al.* (2002).

Procedure

The task involved presentation of two faces side by side on a computer screen. The participant was required to respond according to whether they thought the faces were the same or different, by pressing one of two keys as quickly (but as accurately) as they could. The testing session began with a game and practice trials to ensure that all participants understood the instructions and the meaning of the words 'same' and 'different'. The experimenter played a short game with each child, which involved placing objects that were the 'same' on one side and 'different' separately. Once the experimenter was satisfied that the child understood the rules of the game, the practice trials began. Three upright and three inverted practice trials for each condition preceded the proper test. Thirty trials from the featural and configural sets were presented respectively. Face stimuli were presented simultaneously on a 17-inch computer monitor using SuperLab Pro 2.0 software. Following Mondloch *et al.*'s (2002) procedure, the upright block was always presented before the inverted block and the order of configural and featural blocks within these was counterbalanced across participants. Each block

consisted of 15 'same' (henceforth, identity trials) and 15 'different' (henceforth, transformed trials) in randomised order.

The experimenter initiated the task by saying: '. . .. *Look. This is Jane and these are her sisters. Some sisters look the same because they are twins. Do you know any twins?. . . Some sisters look different and they are not twins. Now we are going to play a game where sometimes you will see twin sisters, sometimes not. When you see two faces that you think look the same, press this button* (experimenter shows the relevant button) *and when you think that the faces look different, press this button* (experimenter shows the relevant button).'

During each trial, two target faces were presented simultaneously until the response button was pressed.[1] Only two keys on the keyboard were visible. Two cards were placed under the relevant key, one had two dots of the same colour (representing 'same' response – S key) and the other card had two different colours (representing 'different' response – L key).

The experimental protocol was approved by the Birkbeck, University of London Ethics Committee prior to recruitment of participants. Both parental informed consent and the child's assent were obtained before participation.

Results

The task comprised two components: *difference detection* (where the difference was due to a either configural or featural transformation) and *identity recognition* (for all trials where no change had been made between model and target). We analysed the difference detection and identity recognition trials for featural and configural blocks separately, as configural/featural transformation only applied to difference detection, whereas upright/inverted orientation applied to all trial types (see Karmiloff-Smith *et al*. 2004 for a similar approach).

Initially, developmental trajectories were constructed linking accuracy to CA for each group. A fully factorial ANCOVA was used, with age as the covariate and orientation (upright, inverted) and, for difference detection, face transformation (configural, featural) as within-participants factors. Each clinical group was then compared with the TD group, by adding a between-participant factor of group to the design. In addition, we performed two planned comparisons. These were: (i) to assess the effect of the severity of autistic symptoms (measured according to CARS test) on face recognition by comparison of the HFA and LFA groups; and (ii) to examine whether the WS and HFA groups responded in a similar way on the Jane faces task, as both disorders have previously been characterised as having a 'featural' approach to face recognition. Finally, we repeated this design, but instead constructed developmental trajectories linking task accuracy with performance on the three standardised tests: face recognition (Benton), receptive vocabulary (BPVS) and visuospatial construction (PC). The first of these was the most relevant as it addressed the key question: for each disorder group, was the normal pattern of face configural processing observed given their level of accuracy on a standardised face recognition task?

Identity recognition

We first deal briefly with performance on trials where the two faces were identical, and the participant should have responded 'same'. Group means per condition are shown in Table 2. No group revealed a main effect of orientation: identity match was equally accurate for pairs of upright and pairs of inverted faces. Whether identity recognition trials were presented in configural or featural blocks had no effect on performance in any of the groups. There was no significant interaction of block type on orientation or any other variables, suggesting that trial-blocking of the featural versus configural condition did not trigger specific face-recognition strategies sufficient to affect identify recognition. A comparison of accuracy levels revealed no significant difference between TD group and HFA group ($F_{1,37} = 2.29$, $P = 0.139$, $\eta_p^2 = 0.11$), nor between TD and DS group ($F_{1,36} = 0.09$, $P = 0.773$, $\eta_p^2 = 0.11$). Children with WS performed reliably better than the TD group on identity recognition

[1] Mondloch *et al*. (2002) presented the stimuli sequentially. However, as impairments in verbal and visuospatial short-term and/or long-term memory have been reported in all three disorders under study (e.g. Minshew & Goldstein 2001; Jarrold *et al*. 2002), the memory component was removed.

Table 2 Means and standard errors (SE) for accuracy % in identity recognition

	Trial block							
	Featural				Configural			
	Upright		Inverted		Upright		Inverted	
Group	Mean %	(SE)%	Mean %	(SE)%	Mean %	(SE)%	Mean %	(SE)%
TD ($n = 25$)	73	3.7	75	3.0	69	3.4	70	2.7
HFA ($n = 16$)	72	3.4	65	4.1	67	4.0	57	4.4
LFA ($n = 17$)	58	3.0	61	3.4	51	4.7	51	4.5
DS ($n = 15$)	63	4.0	57	2.8	61	5.0	56	2.8
WS ($n = 18$)	71	2.4	68	3.5	86	3.6	82	5.2

TD: typically developing; HFA: high-functioning children with autism; LFA: low-functioning children with autism; DS: Down syndrome; WS: Williams syndrome.

Table 3 Means and standard errors (SE) for accuracy % in difference detection

	Trial block							
	Featural				Configural			
	Upright		Inverted		Upright		Inverted	
Group	Mean %	(SE)%	Mean %	(SE)%	Mean %	(SE)%	Mean %	(SE)%
TD ($n = 25$)	81	2.8	79	2.5	62	4.8	23	2.3
HFA ($n = 16$)	79	3.8	80	2.7	42	5.4	47	5.9
LFA ($n = 17$)	60	4.0	63	3.1	22	3.5	17	3.3
DS ($n = 15$)	64	4.1	59	3.6	39	6.0	24	3.9
WS ($n = 18$)	79	2.7	71	2.1	28	4.4	12	4.1

TD: typically developing; HFA: high-functioning children with autism; LFA: low-functioning children with autism; DS: Down syndrome; WS: Williams syndrome.

($F_{1,37} = 7.94$, $P = 0.008$, $\eta_p^2 = 0.18$), while the LFA group performed reliably poorer ($F_{1,38} = 7.51$, $P = 0.009$, $\eta_p^2 = 0.17$).

Difference detection

1. Chronological age

A summary of the mean accuracy levels for each group is provided in Table 3. Figure 2 depicts trajectories for each group in terms of correct percentage accuracy scores plotted against CA. Because of a large number of main effects and interactions, only comparisons directly relevant to the current study will be reported.

TD group. For this stimulus set, participants found it harder to detect configural changes to faces than featural changes ($F_{1,23} = 39.19$, $P < 0.001$, $\eta_p^2 = 0.63$). Developmentally, a different pattern was observed for responses to featural than configural trials. Performance increased on featural

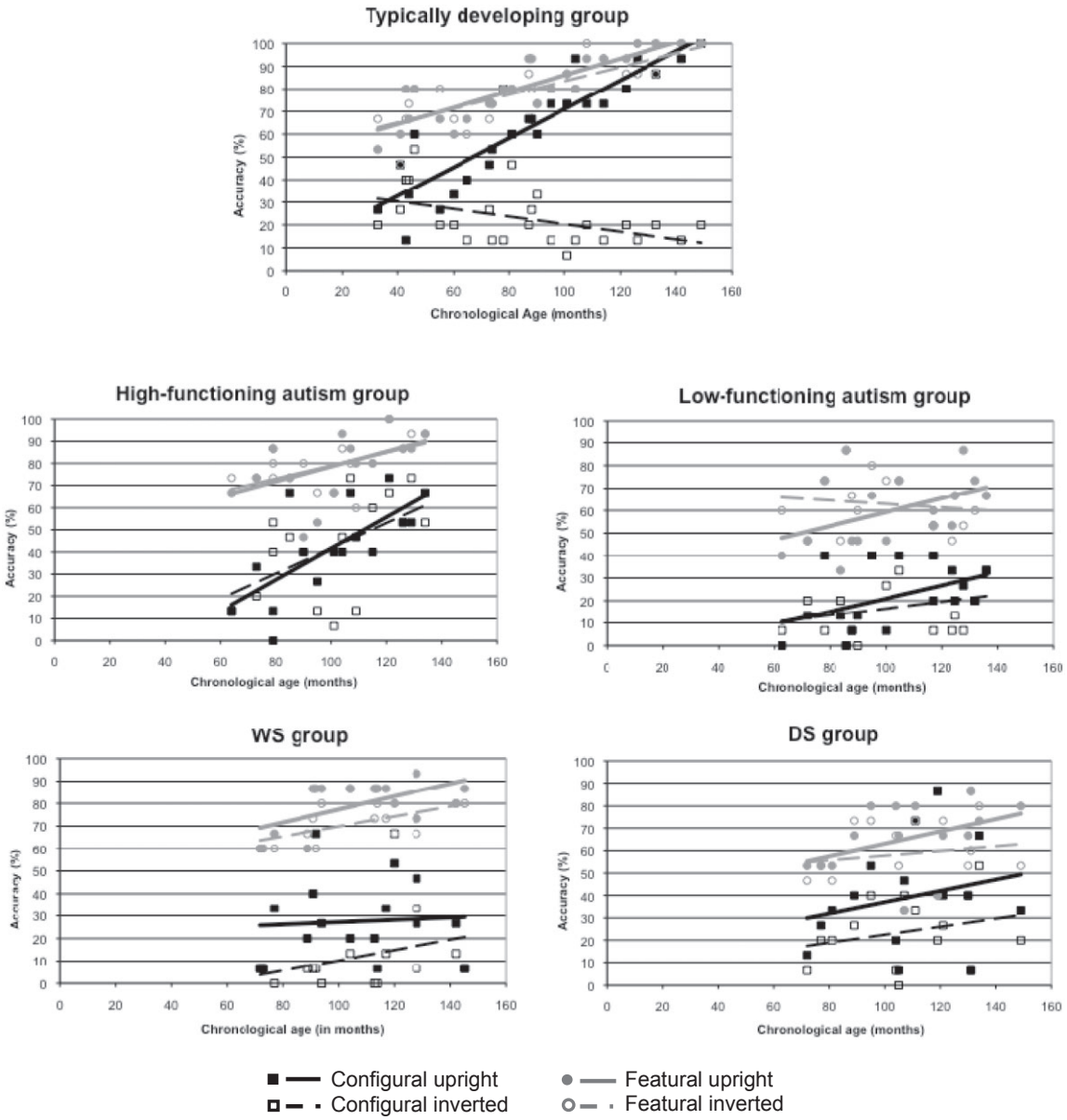

Figure 2 Cross-sectional developmental trajectories for accuracy scores on the Jane faces task plotted against chronological age in months, for each clinical group. DS: Down syndrome; WS: Williams syndrome.

trials with age ($F_{1,23}$ = 63.76, P < 0.001, η_p^2 = 0.74) while orientation of the stimuli had no influence on the accuracy ($F_{1,23}$ = 0.40, P = 0.533, η_p^2 = 0.02). In contrast, on configural trials, a steady increase in accuracy with age was evident for upright faces ($F_{1,23}$ = 23.94, P < 0.001, η_p^2 = 0.51) but a decline in accuracy with age was observed for inverted trials ($F_{1,23}$ = 12.46, P = 0.002, η_p^2 = 0.35; $F_{1,23}$ = 78.00, P < 0.001, η_p^2 = 0.77). This produced a reliable three-way interaction of orientation × transformation type × age ($F_{1,23}$ = 50.89, P < 0.001, η_p^2 = 0.69). For configural trials, the upright and inverted trajectories diverged at 5 years and 8 months (i.e. the point at which the 95% confidence

intervals around the regression lines ceased to overlap). The inversion effect for configural trials emerged shortly before 6 years of age.

HFA group. The HFA group performed more poorly on configural than featural faces ($F_{1,14}$ = 20.21, P < 0.001, η_p^2 = 0.59). Performance on featural trials increased with age ($F_{1,14}$ = 7.42, P = 0.016, η_p^2 = 0.35) and orientation of the stimuli had no influence on performance ($F_{1,14}$ = 0.09, P = 0.764, η_p^2 = 0.10). Performance on configural trials exhibited the same pattern, with a reliable increase across age ($F_{1,14}$ = 14.84, P = 0.002, η_p^2 = 0.52) but no effect of orientation ($F_{1,14}$ = 0.24, P = 0.632, η_p^2 = 0.02). The marker for the emergence of configural processing, an increasing inversion effect with age, was thus absent.

Comparison with TD. The HFA group was overall less accurate in comparison with the TD group ($F_{1,37}$ = 5.41, P = 0.026, η_p^2 = 0.13), indicating a delayed onset in development. Both groups had a similar rate of improvement with age ($F_{1,37}$ = 3.48, P = 0.070, η_p^2 = 0.10), but at the marginal level. Inversion effects emerged differently in the two groups across age ($F_{1,37}$ = 6.18, P = 0.018, η_p^2 = 0.14), and a reliable four-way interaction including trial type confirmed that this was due to the lack of an emerging inversion effect for configural trials ($F_{1,37}$ = 5.12, P = 0.030, η_p^2 = 0.12).

As a more sensitive comparison of the rate of development, we focused on group differences on upright trials. This is because group overlap could result either from delayed improvement on upright trials in the clinical group or from the normal decline in performance on inverted configural trials in the TD group. Focusing on configural upright faces, the HFA group was marginally less accurate in comparison with the TD group ($F_{1,37}$ = 4.21, P = 0.047, η_p^2 = 0.11), indicating a delayed onset in development, but had similar rate of improvement with age ($F_{1,37}$ = 0.16, P = 0.689, η_p^2 = 0.04). In contrast, there were no differences on the featural upright faces between the groups (all P > 0.05).

LFA group. The LFA group displayed the most variability in the performance of all the clinical groups. In line with the other groups, the LFA group exhibited a greater difficulty in the recognition of configurally transformed faces than featurally transformed faces ($F_{1,15}$ = 8.01, P = 0.013, η_p^2 = 0.35). Overall performance did not improve with age ($F_{1,15}$ = 3.07, P = 0.100, η_p^2 = 0.17) but this masks one surprising interaction. Strikingly, for featural trials, performance was initially better on inverted than upright trials. Inverted performance then declined with age, while that on upright trials improved, with the two trajectories crossing over around 9 years of age ($F_{1,15}$ = 8.64, P = 0.010, η_p^2 = 0.37; negative gradient for inverted trials with age: $F_{1,15}$ = 9.45, P = 0.008, η_p^2 = 0.39). That is, for featural trials, until the age of 9, young children in the LFA group performed better on inverted trials than upright ones (Table 2). For configural trials, neither effects of age nor orientation nor their interaction were reliable (all P > 0.1).

Comparison with TD. The LFA group had lower overall performance compared with the TD group. However, there were neither reliable differences in the onset of development nor rate of improvement across age (all P > 0.05) The groups showed a different relationship in the way inversion altered performance across age ($F_{1,38}$ = 33.32, P < 0.001, η_p^2 = 0.47), an interaction that was observed separately for featural and configural trials ($F_{1,38}$ = 7.13, P = 0.010, η_p^2 = 0.17; $F_{1,38}$ = 14.97, P < 0.001, η_p^2 = 0.29). LFA group did not exhibit the hallmark of the development of configural processing – the emerging inversion effect ($F_{1,38}$ = 26.37, P < 0.001, η_p^2 = 0.41).

Also configural upright trials indicated a similar onset in development of both groups ($F_{1,38}$ = 1.02, P = 0.318, η_p^2 = 0.02), but had slower rate of improvement with age ($F_{1,38}$ = 5.28, P = 0.027, η_p^2 = 12.). There were no group differences on the featural upright faces (all P > 0.1).

DS group. The DS trajectories exhibited the familiar pattern of better accuracy on featural over configural trials ($F_{1,13}$ = 13.34, P = 0.004, η_p^2 = 0.57). Overall, presentation of the faces in different orientations had no influence on accuracy levels ($F_{1,13}$ = 0.01, P = 0.946, η_p^2 = 0.01) and performance did not improve reliably with age

($F_{1,13}$ = 3.00, P = 0.106, η_p^2 = 0.19). This pattern held when featural and configural trials were analysed separately.

Comparison with TD. The DS group improved significantly more slowly with age in comparison with TD ($F_{1,36}$ = 18.62, P < 0.001, η_p^2 = 0.34), but no reliable statistical group difference emerged in the onset (P > 0.05). Also, the DS group was less affected by stimulus orientation ($F_{1,36}$ = 10.11, P = 0.003, η_p^2 = 0.22). This overall effect stemmed from the lack of an emerging inversion effect for configural trials ($F_{1,36}$ = 12.87, P < 0.001, η_p^2 = 0.26). On the upright configural faces, both groups had similar onset (P > 0.1), but a slower rate of development in the DS group approached significance ($F_{1,36}$ = 3.84, P = 0.058, η_p^2 = 0.10). No group differences were apparent on upright featural trials (P > 0.1).

WS group. As with the other groups, children in the WS group found it easier to detect featural alterations between faces than configural changes ($F_{1,14}$ = 5.68, P = 0.032, η_p^2 = 0.29). Accuracy increased with age ($F_{1,14}$ = 6.07, P = 0.027, η_p^2 = 0.30), but was not influenced by orientation ($F_{1,14}$ = 1.46, P = 0.247, η_p^2 = 0.10). Neither did these two factors interact. This pattern was also found when featural and configural trials were analysed individually, with the exception that performance on configural trials was poor and did not improve with increased age ($F_{1,14}$ = 0.92, P = 0.354, η_p^2 = 0.10).

Comparison with TD. The WS group had lower overall performance compared with the TD group. However, there were neither reliable differences in the onset of development nor rate of improvement across age (all P < 0.05). The inversion effect for configural faces was absent in WS ($F_{1,37}$ = 27.06, P < 0.001, η_p^2 = 0.421). The WS group had similar onset in development on the configural upright faces in comparison with the TD group (P > 0.1), but rate of improvement with age on the configural trials was slower ($F_{1,37}$ = 11.19, P = 0.002, η_p^2 = 0.23). No group differences were apparent on upright featural trials (P > 0.1).

Intra- and inter-clinical group comparisons

Autism groups. The autism groups were compared to investigate the influence of the severity of the disorder on configural processing. Overall, there was no main effect of group ($F_{1,29}$ = 0.46, P = 0.504, η_p^2 = 0.02). However, the HFA group exhibited a faster rate of improvement over development ($F_{1,29}$ = 4.92, P = 0.035, η_p^2 = 0.15). For featural faces, a differential effect of inversion was apparent. As we noted previously, for the LFA group, inverted faces are initially processed more accurately but this declines with age, whereas the HFA group did not show this pattern ($F_{1,29}$ = 4.67, P = 0.039, η_p^2 = 0.14).

The two autism groups represent a categorical distinction based on symptom severity. As a complementary analysis, we combined the groups and employed the CARS score as an additional covariate along with CA. CARS score predicted a reliable proportion of variance in task accuracy ($F_{1,29}$ = 5.01, P = 0.033, η_p^2 = 0.15). It did not modulate either effects of transformation or orientation, showing only a trend to modulate the way that CA influenced orientation, the same three-way interaction that was identified in the categorical group comparison ($F_{1,29}$ = 3.76, P = 0.062, η_p^2 = 0.12).

HFA and WS. Autism and WS have both been characterised as exhibiting featural face recognition. A comparison of HFA and WS groups indicated no overall group difference ($F_{1,28}$ = 1.16, P = 0.292, η_p^2 = 0.04), although the WS group showed a slower rate of improvement with age (effect of age × group: $F_{1,28}$ = 42.7, P = 0.048, η_p^2 = 0.13). Separate analysis of conditions revealed a similar pattern of development on featural sets ($F_{1,28}$ = 0.06, P = 0.813, η_p^2 = 0.02), but the HFA group showed faster rate of development on configural trials (age × group: $F_{1,28}$ = 4.71, P = 0.039, η_p^2 = 0.14). The deficit in configural processing therefore appeared to be more severe in the WS group than the high-functioning autism group. In contrast, LFA group showed similar performance with age on configural trials (age × group: $F_{1,29}$ = 0.71, P = 0.49, η_p^2 = 0.19) but the WS group was significantly faster on featural trials ($F_{1,29}$ = 4.96, P = 0.01, η_p^2 = 0.22). No other group comparisons showed significant outcomes.

2. Mental age

Three MA measures were taken. We repeated the preceding analyses but for brevity of exposition, these are summarised in two ways. First, Table 4 depicts the proportion of variance explained by each predictor for each group.

The TD group demonstrated the strong predictive power of all MA measures, although in TD these measures are strongly correlated with CA. In the HFA group, accuracy on the Jane task was best predicted by performance on Benton test, which predicted performance as well as CA. Severity of autism symptoms on the CARS was a better predictor of performance than BPVS, which was also the case in the LFA group. This validated our choice of symptom severity to distinguish the autism groups rather than verbal ability. The LFA group showed no reliable predictive power of any age or MA measure as a main effect, but these covariates did appear in reliable interactions with orientation (CA analysis) or transformation × orientation (Benton, PC). The WS group showed the strongest predictive power of BPVS, perhaps because relatively strong receptive language is a good (inverse) marker of severity in this clinical group. In DS, no measure was a reliable predictor as a main effect, although once more, predictors appeared in reliable interactions: in both BPVS and PC analyses for the DS group, the MA measure reliably modulated the interaction of transformation × orientation, with an increasing inversion effect for detecting featural transformations as MA increased, but a decreasing inversion effect for detecting configural transformations (the opposite of the TD pattern).

Second, we examined whether the configural effect was or was not appropriate for the level of face ability based on the Benton test. When the covariate is switched to the performance scores on the Benton task, the comparison of the disorder group to the TD group should render the main effect of group, and all interactions involving group, non-significant. Disorder group trajectories should look no different from the (relevant proportion of the) TD trajectories.

This did not occur for any disorder. Atypicalities identified in CA analyses remained and was observed on all MA measures (Figs 3–5). One caveat must be mentioned. The unevenness of the cognitive profiles across MA measures compromised some of these analyses by truncating the range of variation (e.g. BPVS in DS, PC in WS and DS) and therefore the trajectory overlap in group comparisons. Nevertheless, across Figs 2–5, against the consistent presence of the effect of

Table 4 Effect size (η_p^2) of the main effect of the covariate in fully factorial ANCOVAs predicting performance on the Jane faces task, with factors of transformation (configural/featural), orientation (upright/inverted), and interactions between factors and covariate, for analyses with five different covariates: (i) chronological age; (ii) face recognition ability according to the Benton test; (iii) receptive vocabulary mental age according to the BPVS; (iv) visuospatial construction mental age according to PC; and (v) for the two autism groups, symptom severity according to the Childhood Autism Rating Scale. For the autism groups, analyses were either carried out with the groups split categorically according to severity or combined into a single group

Group	Chronological age (months)	Benton raw score	BPVS standard score (months)	PC standard score (months)	Childhood Autism Rating Scale
TD	0.722**	0.568**	0.740**	0.640**	
HFA	0.522**	0.541**	0.154	0.240	0.398**
LFA	0.170	0.000	0.001	0.126	0.174
Autism (combined)	0.163*	0.332**	0.284**	0.099	0.520**
WS	0.302*	0.170	0.558**	0.283*	
DS	0.188	0.075	0.002	0.002	

** $P < 0.01$, * $P < 0.05$.

TD: typically developing; HFA: high-functioning children with autism; LFA: low-functioning children with autism; WS: Williams syndrome; DS: Down syndrome; Benton score: raw score on Benton Face Recognition Test (Benton *et al.* 1983); BPVS: British Picture Vocabulary Scale (Dunn *et al.* 1997); PC: Pattern Construction subtest of the British Abilities Scale II (Elliot *et al.* 1997).

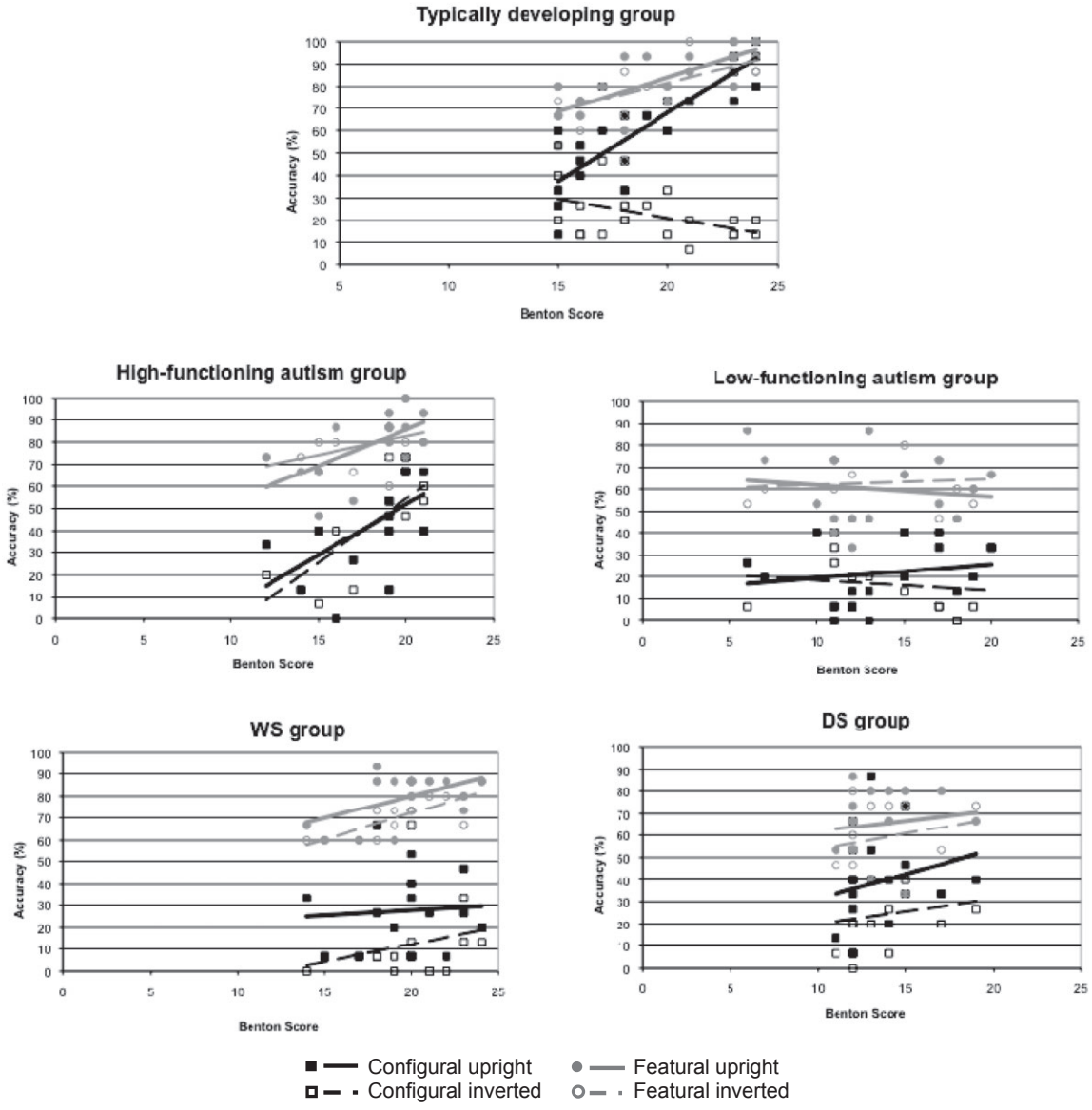

Figure 3 Cross-sectional developmental trajectories for accuracy scores on the Jane faces task plotted against raw score on the Benton face recognition test (Benton *et al.* 1983), for each clinical group. DS: Down syndrome; WS: Williams syndrome.

transformation type, markers of atypicality remained: the lack of an inversion effect in HFA, the changing interaction of transformation and orientation across age in LFA, and the absence across all disorder groups of the emerging inversion effect for detecting configural transformations so evident in the TD trajectories.

Discussion

In our study, cross-sectional developmental trajectories for detecting configural changes in upright versus inverted faces reliably diverged by around 6 years of age for the TD group. This pattern is consistent with previous findings (e.g. Leder & Bruce

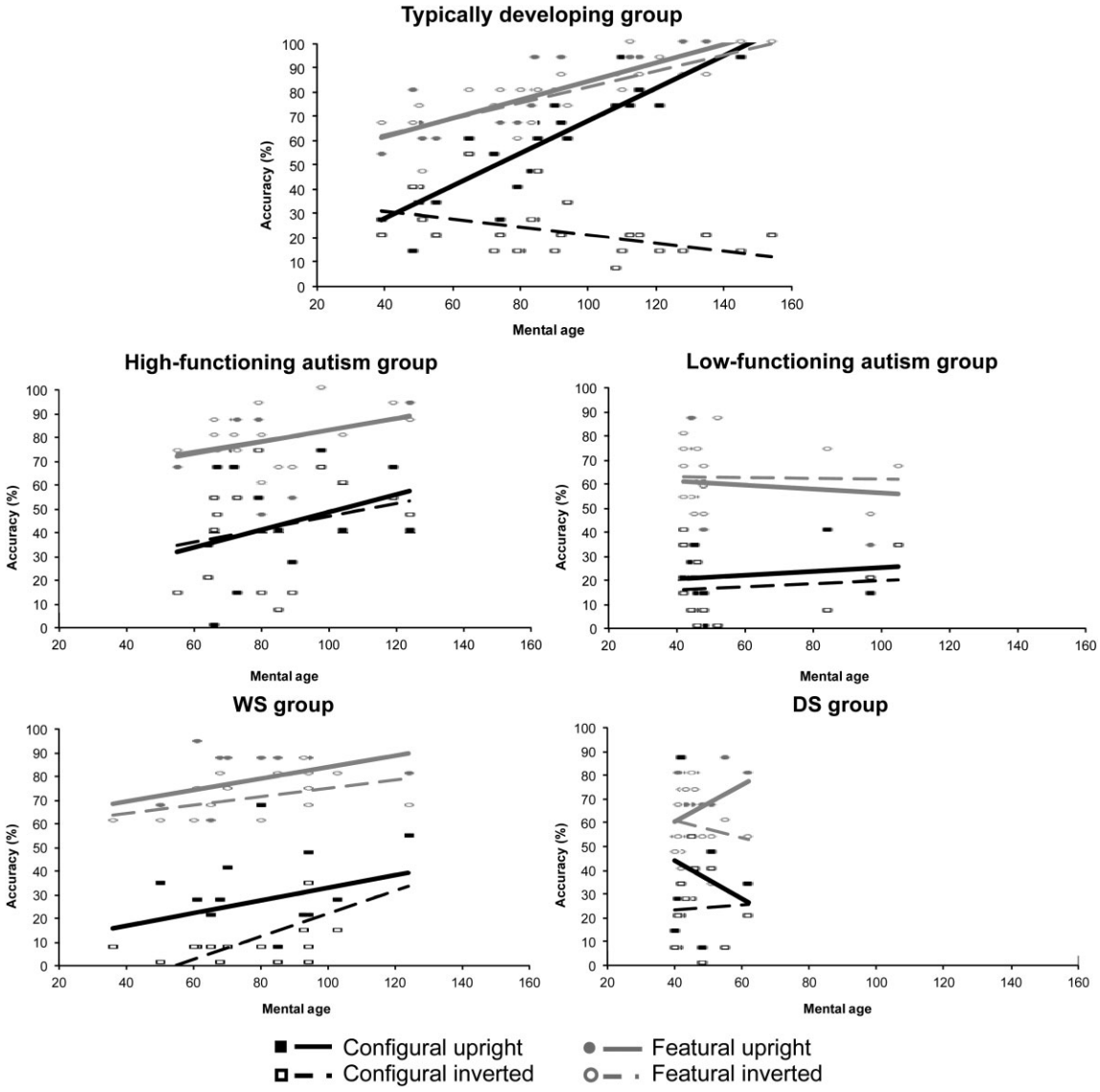

Figure 4 Cross-sectional developmental trajectories for accuracy scores on the Jane faces task plotted against test age in months on the British Picture Vocabulary Scale (Dunn *et al.* 1997), for each clinical group. DS: Down syndrome; WS: Williams syndrome.

2000; Mondloch *et al.* 2002; see also Slessor *et al.* 2013).

The HFA group did not show inversion effect on either featurally or configurally altered faces, while task performance improved robustly across the 5–11 years range examined. Children in the LFA group performed at a much lower level and developed more slowly. Once more, no inversion effect was observed for configurally altered faces. However, interestingly, for featurally altered faces, the youngest children in the LFA group found it easiest to make the discrimination for inverted rather than upright faces, a unique pattern among all the groups. A similar pattern was reported in a different task involving holistic processing (Annaz *et al.* 2009), and also in a study by Hobson *et al.* (1988),

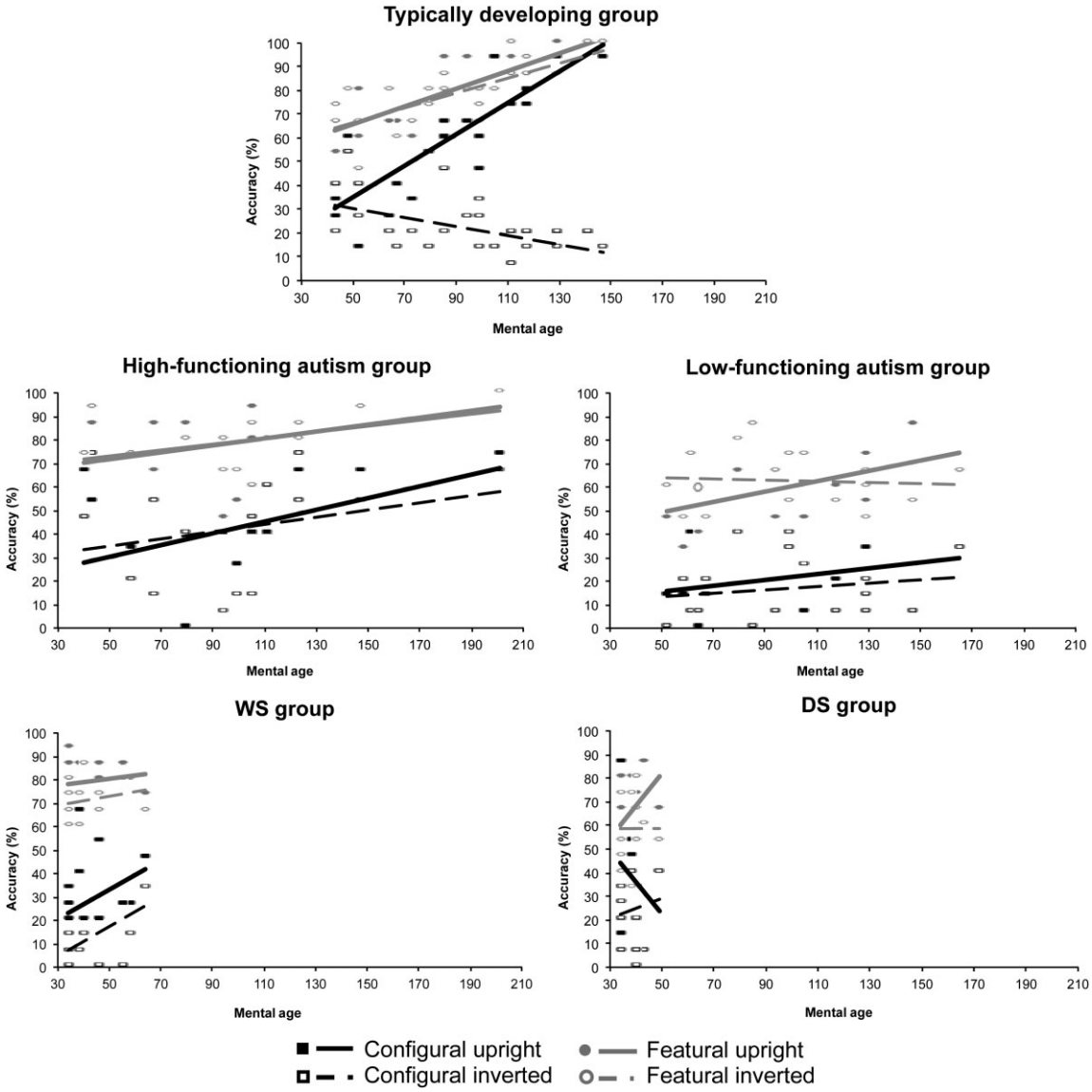

Figure 5 Cross-sectional developmental trajectories for accuracy scores on the Jane faces task plotted against test age in months on the Pattern Construction (PC) test from the British Abilities Scale II (Elliot *et al.* 1997), for each clinical group. DS: Down syndrome; WS: Williams syndrome.

suggesting this unusual effect is a real one. Its likely that an aversion to upright faces or the eye region of upright faces in LFA drives their attention on inverted faces.

A recent review of face recognition in autism by Weigelt *et al.* (2012) concluded that face processing in autism was not qualitatively different from TD but was *quantitatively* poorer. We did not find that result here as the absence of configural inversion effects in both autism groups. The presence of a featural inversion effect in the LFA group appear *qualitatively atypical*, even when cross-sectional trajectories were constructed in relation to performance on a standardised test of face recognition. Weigelt, Koldewyn and Kanwisher's conclusion was based on reviewing the literature on markers of

typical face processing, including the following effects such as inversion, part–whole, composite, inner versus outer features and face space. It is notable that of these, the face-space marker, which is a clear index of configural processing, showed the strongest evidence of qualitative differences (see Weigelt *et al.* 2012, fig. 1). The current data, then, are in line with the view that configural processing may be the most (or only) qualitatively atypical characteristic of face recognition in autism, and may point to a greater exploitation of featural processing.

Face recognition in WS were suggestive of an effect of inversion, but it was far from reliable, and nor did it emerge across development in the configural condition. Configural processing was slow to develop, more so than in the HFA group. The interpretation then, is that configural processing represents a particular deficit in the WS group (Karmiloff-Smith *et al.* 2004). Yet despite poor configural processing, the WS group score on a par with the HFA group on the Benton test of face recognition.

The DS group showed poor performance, revealing only slight improvement across age. Again, there was no evidence of the emerging inversion effect in the configural condition, contrary to what is observed in TD. (In two of the MA analyses, an inversion effect emerged in featural processing.) This result, along with previous reports (Wishart & Pitcairn 2000), points overall to poor face recognition abilities in DS. Despite the sometimes characterisation of DS as exhibiting a 'global' visuospatial processing style (e.g. Bellugi *et al.* 2000), this did not manifest in a configural processing advantage in the current study.

When developmental trajectories were constructed linking task performance against performance on the Benton task, the main results still held. This supports the view that the differences between groups were not due to different levels of face recognition ability. Some caution is required here, as the Benton test can be performed using a pixel-matching strategy instead of a face-identity matching strategy (Duchaine & Nakayama 2004). Nevertheless, for the lack of an inversion effect in the configural condition to have been explained by delay alone, no disorder group would need to have face recognition abilities that exceeded those of a 6-year-old, something we deem unlikely for the children tested here.

Overall, our findings are consistent with the view that configural processing is developmentally vulnerable, as we did not find markers of its presence in any of our clinical groups. The data nevertheless suggest that there are alternative developmental pathways to achieve relatively good performance levels in face recognition. However, these differ between the clinical groups.

Within the clinical developmental viewpoint, atypical development and TD are mutually informative. In the current study, atypical development informed TD in the following way. The TD of face recognition appears to be constrained by (i) the initial low-level granularity of visual input, established by early developmental processes; (ii) the emergence of new representations to support expert level performance, driven by experience of faces; and (iii) motivation to attend to faces, thereby gaining this experience. TD informed atypical development by showing the impact of variations in these constraints. In HFA, experience is not markedly disrupted, and finer scale low-level visual granularity allows good face recognition without the emergence of new representations. In LFA, experience with faces is disrupted by atypical attendance to social cues, impairing the development of face recognition. In WS, deficits to the visuospatial system prevent the emergence of new representations underlying expertise, but sufficient practise drives another processing solution to support good face recognition. In DS, this solution is not possible despite an equivalent interest in faces, possible because the low-level granularity of features is too coarse.

Our study highlights the importance of cross-syndrome approach which revealed the constraints that shape the TD of face recognition. The relative balance of featural and configural processing as strategies to drive recognition, the protracted developmental trajectory of configural processing as a pathway to drive expert levels of recognition, and the influence of motivation factors in perceiving faces and providing the input to driving improving recognition. Atypical configural recognition may have cascading effects on other skills within the face processing domain such as emotion recognition and potentially far reaching

implications beyond the field of face recognition by negative influence on social communication.

There are a number of limitations that must be borne in mind when evaluating the current results. The current data are cross-sectional and use of longitudinal approach could potentially give a better picture in terms of developmental changes of individuals and effects of individual variability. Participants came from uniform socioeconomical backgrounds of similar environmental stimulations, hence eliminating generalisation of the current results into the general population. Finally, this study included only school age children thus future research into cross syndrome comparisons could extend age into adolescence. Lastly, use of multidisciplinary approach such as endocrine analyses, could increase our understanding of atypical face recognition abilities in clinical populations. These in turn, could be used in a more effective way to improve and implement educational strategies for clinical groups.

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Accepted 30 May 2014