Missing the Big Picture: Impaired Development of Global Shape Processing in Autism

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Individuals with autism exhibit hypersensitivity to local elements of the input, which may interfere with the ability to group visual elements perceptually. We investigated the development of perceptual grouping abilities in high-functioning individuals with autism (HFA) across a wide age range (8–30 years) using a classic compound letter global/local (GL) task and a more fine-grained microgenetic prime paradigm (MPP), including both few- and many-element hierarchical displays. In the GL task, contrary to the typically developing (TD) controls, HFA participants did not develop an increasing sensitivity to the global information with age. In the MPP, like the TD controls, individuals with autism at all three age groups evinced a bias to individuate the few-element displays. However, contrary to the TD controls, the HFA group failed to show age-related improvements in the ability to encode the global shape of the many-element displays. In fact, across the age range, the HFA group was consistently faster than the TD controls at perceiving the local elements in these displays. These results indicate that in autism the full process of garnering shape information from perceptual grouping, which is essential for the ability to do fast and efficient object recognition and identification, never matures, and this is especially evident in adolescence when this ability begins to improve in TD individuals. The atypical development of these perceptual organizational abilities may disrupt processing of visually presented objects, which may, in turn, fundamentally impede the development of major aspects of the social and emotional behaviors in individuals with autism.

Keywords: perceptual grouping; global/local processing; vision; global advantage

The ability to organize visual input coherently is fundamental to a host of more complex perceptual processes. For example, the perceptual ability to group the individual features of a face into a holistic shape is critical for identity and emotion expression recognition. Impaired face identity and emotion expression recognition are some of the most widely cited deficits in autism [Joseph & Tanaka, 2003; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Lahaie et al., 2006; Pellicano, Jeffery, Burr, & Rhodes, 2007], which may be directly related to atypical perceptual organization abilities.

Perceptual Organization in Individuals With Autism

Individuals with autism exhibit hypersensitivity to local elements of the input [Caron, Mottron, Berthiaume, & Dawson, 2006; Mottron, Burack, Iarocci, Belleville, & Enns, 2003], which may interfere with the ability to group visual elements perceptually. For example, compared to typically developing (TD) individuals, those with autism (autism spectrum disorder (ASD)) exhibit superior abilities to detect local targets in visual search tasks [Plaisted, O'Riordan, & Baron-Cohen, 1998], ignore the influence of increasing numbers of distracters during visual search [O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001], and identify fine stimulus features in spatial tasks like the Wechsler block design and embedded figures task [Caron et al., 2006; Jolliffe & Baron-Cohen, 1997; Mottron et al., 2003; Shah & Frith, 1993]. At the same time, individuals with autism appear to be limited in their ability to derive organized wholes from perceptual parts, which has been linked to their limited use of gestalt grouping heuristics [Brosnan, Scott, Fox, & Pye, 2004], the failure to process inter-element relationships [Behrmann et al., 2006], and/or the failure to consider the entire visual context [Happé, 1996]. Several studies have argued that this focus on local features is specifically detrimental to face recognition processes [Boucher & Lewis, 1992; Davies, Bishop, Manstead, & Tantam, 1994; Hobson, Ouston, & Lee, 1988; Joseph & Tanaka, 2003; Klin et al., 2002; Lahaie et al., 2006].

This atypical sensitivity to local elements has been addressed in two theoretical frameworks. The Weak

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Central Coherence (WCC) theory posits that in ASD there is a strong bias to process featural and local information and a core deficit in the ability to integrate local information into a coherent global gestalt [Frith, 1989; Frith & Happé, 1994; Happé & Frith, 2006]. Alternatively, the Enhanced Perceptual Functioning (EPF) model hypothesizes that autism is characterized by an atypical relationship between higher- and lower-order cognitive processes, in that lower-level perceptual processes (i.e., processing of local information) are more developed, which is disruptive to the development of the higher-order processes [Mottron & Burack, 2001; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006]. In sum, the WCC theory emphasizes a deficit in global processing and the EPF theory emphasizes the superiority of local processing. Neither of these theories has proposed how or when developmentally the superior processing of local information becomes the prominent processing style in autism and it is this issue that is the focus of the current investigation.

A large number of developmental studies investigating both face processing and basic visuoperceptual processing in autism have produced inconsistent outcomes. While some conclude that children with autism exhibit limited abilities to integrate local elements into a coherent global shape [Plaisted et al., 1999; Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2000; Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2001; Wang, Mottron, Peng, Berthiaume, & Dawson, 2007], others report typical processing of both the global and local information in hierarchical visual stimuli [Deruelle, Rondon, Gepner, & Fagot, 2006; Iarocci, Burack, Shore, Mottron, & Enns, 2006; Mottron et al., 2003; Ozonoff, Strayer, McMahon, & Filloux, 1994; Plaisted, Dobler, Bell, & Davis, 2006]. Part of the discrepancy in these findings may be related to the inclusion of a broad range of ages in the same study and a heterogeneous sample of participants. For example, in all of the previous developmental studies, the age of the participants ranged from late childhood (in some cases with participants as young as 4 years of age) through early adulthood. Several studies included participants in the full range of ASD [Deruelle et al., 2006; Rinehart et al., 2000, 2001] and others included autism participants with Full Scale IQ (FSIQ) scores below 70 and intellectually impaired IQ-matched controls [Wang et al., 2007]. Such a variability may have prevented researchers from observing subtle developmental differences in information processing biases between the autism and control groups. Furthermore, in several of the previous studies, TD participants also failed to show sensitivity to the global information in the hierarchical stimuli [Mottron et al., 2003; Mottron, Burack, Stauder, & Robaey, 1999; Rinehart et al., 2001]. This is especially relevant since there is considerable debate about the developmental trajectory of perceptual organization in TD individuals.

Development of Perceptual Organization in Typical Individuals

Much of the work on the development of perceptual organization in TD individuals suggests that infants are capable of grouping visual elements into unitary structures using foundational Gestalt algorithms [e.g., Farroni, Valenza, Simion, & Umilta, 2000; Johnson & Aslin, 1995; Quinn & Bhatt, 2006]. However, studies with older children suggest that there is a protracted developmental trajectory for the ability to integrate local visual features spatially across the visual field [Hadad & Kimchi, 2006; Kovács, 2000; Kovács, Kozma, Feher, & Benedek, 1999]. In particular, several studies have reported that sensitivity to global structure in hierarchical visual stimuli, in which multiple levels of structure co-exist from the local elements to the global structure, is not fully mature even in late childhood and early adolescence [Burack, Enns, Iarocci, & Randolph, 2000; Dukette & Stiles, 1996; Enns, Burack, Iarocci, & Randolph, 2000; Mondloch, Geldart, Maurer, & de Schonen, 2003; Mottron et al., 1999; Porporino, Shore, Iarocci, & Burack, 2004].

More recently, evidence suggests that perceptual organization is not developmentally monolithic and that there are multiple processes, which develop along different trajectories [Behrmann & Kimchi, 2003; Kimchi, Hadad, Behrmann, & Palmer, 2005; Scherf, Behrmann, Kimchi, & Luna, 2008]. Of particular relevance for the current study are the findings that the ability to individuate elements within hierarchical displays matures earlier than does the ability to group the elements to perceive a global shape [Kimchi et al., 2005; Scherf et al., 2008]. Furthermore, these late developing perceptual grouping abilities may, themselves, reflect the culmination of multiple processes that develop along different trajectories. For example, previous studies with adults have contrasted element clustering and shape formation as two different kinds of perceptual grouping [Razpurker-Apfeld & Kimchi, 2007; Trick & Enns, 1997; see also Koffka, 1935]. Element clustering involves determining which elements belong together, whereas shape formation involves determining cluster boundaries. The process of element clustering is facilitated when the number of elements increases and their relative size decreases, both for adults [Bacon & Egeth, 1991; Banks & Prinzmetal, 1976; Kimchi, 1998] and children [Dukette & Stiles, 1996, 2001; Kimchi et al., 2005; Plaisted et al., 2006]. Recent studies with typical children suggest that element clustering develops fairly early, whereas shape formation develops into late adolescence [Kimchi et al., 2005; Scherf et al., 2008].

This set of results in TD children lead to some interesting predictions about atypical development of perceptual organization abilities in children with autism that have not been previously suggested in either the

WCC or EPF frameworks. Given the evidence of extreme sensitivity to local details, children with autism may develop perceptual individuation abilities in a similar fashion and along a similar timeline as do TD children. However, this same sensitivity may interfere with the ability to develop perceptual grouping, which may include either and/or both element clustering and global shape formation. Furthermore, these differences may not be observable until adolescence when perceptual grouping processes, and shape formation in particular, are beginning to mature and stabilize in TD individuals. According to this framework, contrary to the EPF predictions, we would not expect to see superior processing of local details in all tasks, but only in those that require perceptual grouping. Additionally, contrary to the WCC predictions, we would not expect to observe impairments on all tasks that require integration of local elements since perceptual grouping abilities are not homogeneous.

Purpose of the Present Research

The goal of these studies was to evaluate systematically the development of local element and global shape processing in autism from late childhood, when these processes are still maturing in TD children, through early adulthood. To do so, we conducted two cross-sectional experiments with high-functioning individuals with autism (HFA) and matched TD controls across a wide age range (8–30 years). We controlled the age span within three developmental groups that map onto ages during which important transitions in perceptual organization abilities occur in TD individuals [Kimchi et al., 2005; Scherf et al., 2008].

Study 1: Global/Local Processing of Compound Letters

In our first experiment, we used the well-known hierarchical compound stimuli [Navon, 1977]. TD adults characteristically exhibit a global advantage (i.e., faster identification of the global letter and asymmetric global-to-local interference) when performing this task. We used a focused attention version of the task in which participants identify the global or local letter in separate blocks since divided attention versions reduce the precedence of global information for TD adults [Hoffman, 1980; Kimchi, Gopher, Rubin, & Raij, 1993].

Methods

Participants

Table I. Demographic Characteristics of Typically Developing (TD) and High-Functioning Autism (HFA) Participants

								ADOS		
Age	Group	***N***	Males	Age	VIQ	PIQ	FSIQ	C	S	T
Children										
	HFA	15	15	10 (1)	102 (12)	108 (15)	105 (11)	5 (1)	9 (2)	14 (2)
	TD	15	10	11 (1)	106 (11)	106 (12)	107 (9)			
Adolescents										
	HFA	15	14	15 (1)	104 (15)	109 (12)	107 (13)	5 (3)	8 (2)	14 (3)
	TD	15	13	15 (1)	109 (10)	109 (10)	110 (11)			
Adults										
	HFA	9	8	28 (7)	108 (17)	106 (17)	109 (17)	5 (1)	9 (2)	14 (3)
	TD	9	9	28 (8)						

Cells contain mean scores and (SD). IQ scores were not measured for TD adults, whose data have already been published as a comparison group for the HFA adults [Behrmann et al., 2006]. Independent samples ***t***-tests comparing age and IQ scores within each age group failed to reveal any significant differences between the TD and HFA groups. ADOS, autism diagnostic observation schedule; VIQ, verbal IQ; PIQ, performance IQ; FSIQ, Full Scale IQ; C, communication; S, social; T, total.

The participants included 39 HFA (IQ>80) (15 children, 15 adolescents, 9 adults) and 39 TD control participants (see Table I). Results from the TD individuals [Scherf et al., 2008] and both groups of adults [Behrmann et al., 2006] were previously published and are included here to indicate the typical developmental profile and the mature end point of perceptual processing. Written informed consent was obtained from participants and/or their legal guardians using procedures approved by the institutional review boards of the University of Pittsburgh and Carnegie Mellon University.

The diagnosis of autism was established using the Autism Diagnostic Interview Revised (ADI-R) [Lord, Rutter, & Le Couteur, 1994], the Autism Diagnostic Observation Schedule [Lord, Rutter, DiLavore, & Risi, 2001], and the expert clinical diagnosis [Minshew, 1996]. The individuals with HFA, recruited from autism conferences and parent support groups, were medically healthy and had no identifiable genetic, metabolic, or infectious etiology for their disorder. Participants were also free of birth or traumatic brain injury, seizures, attention deficit disorder, and depression. Their personal and family health histories were evaluated in the initial screening interview and in the medical review portion of the ADI. IQ was determined for all participants using the Wechsler Abbreviated Scale of Intelligence.

TD adults were recruited through advertisements posted on the web, in newspapers, and on local community bulletin boards. Although IQ measures were not collected from these adults, it is unlikely that they had significantly higher FSIQs than the adults with autism.

TD participants were matched to the HFA group on age and sex. Additionally, children and adolescents were matched to HFA participants on FSIQ (see Table I) and were recruited via advertisements given to them at school to take home to their parents. TD participants were included if they were in good physical health, free of regular medication usage, and had good peer relationships as determined by parent or self-report and staff observations during the screening procedures, and did not exhibit behavioral symptoms that could be indicative of autism or any psychiatric diagnosis (as determined via a behavioral checklist completed by a parent).

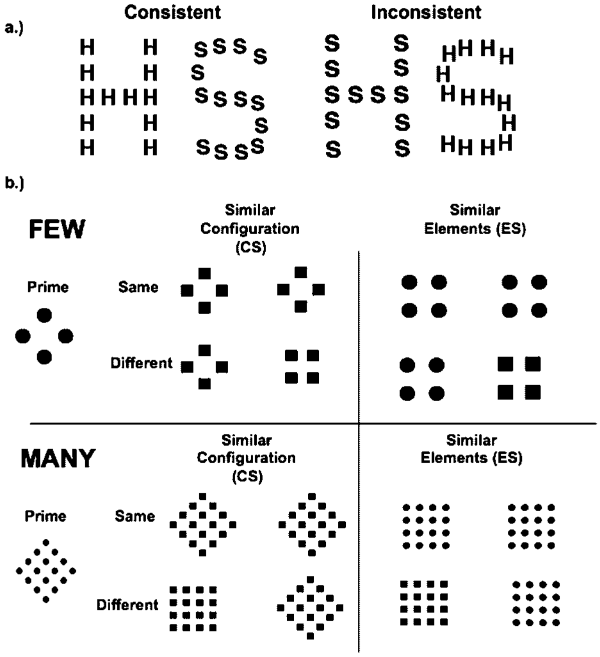

Figure 1. (*a*) The compound letter stimuli used in the global/local task to evaluate developmental differences in sensitivity to global (big letter) and local (small letters) information. (*b*) The hierarchical shape stimuli used in the microgenetic priming task (few- and many-element).

Design and Procedure

The experiments were conducted on a Dell Inspiron 3200 (14-in monitor) laptop computer (Round Rock, TX) and were executed with E-Prime software version 1.1 (Pittsburgh, PA) [Schneider, Eschman, & Zuccolotto, 2001]. Participants made keyboard responses. Reaction time (RT), measured from the onset of the stimulus choice screen, and accuracy were recorded for all tasks. The stimuli included four hierarchical letters of two types: *consistent*, in which the identity of the global and local letters are the same, or *inconsistent*, in which the identity of the letters differed at the two levels (see Fig. 1a). The global letter subtended 3.2° in height and 2.3° in width, and the local letter subtended 0.44° in height and 0.53° in width.

The two tasks, global or local letter identification, were administered in separate blocks of 96 experimental trials each, preceded by 10 practice trials, for a total of 192 trials. There were an equal number of consistent and inconsistent stimuli, which were randomized within a block. To ensure that the participants could identify both the local and global identities, before the experiment began, children and adolescent participants manually traced with their finger the "big" letter and the "little" letter in a consistent and an inconsistent stimulus. If participants had difficulty doing so, the experimenter traced each kind of letter in each stimulus with her own finger and then asked the participant to do so. Each trial started with a central fixation cross for 500 msec. One of the four possible stimuli immediately replaced the fixation and remained on the screen until a response was made. Participants were instructed to press the "s" key with their left index finger or the "h" key with their

Table II. Reaction Time Data for Global/Local Task with Compound Letter Stimuli

		Global			Local		
Age	Group	Inconsistent	Consistent	Interference	Inconsistent	Consistent	Interference
Children							
	HFA	976 (244)	914 (205)	1.6% (4.4)	991 (367)	935 (284)	1.3% (3.9)
	TD	881 (170)	778 (149)	3.2% (1.6)	818 (231)	772 (224)	1.4% (1.6)
Adolescents							
	HFA	701 (218)	613 (141)	2.7% (2.7)	667 (184)	618 (179)	2.0% (2.3)
	TD	666 (120)	612 (109)	2.3% (1.6)	601 (82)	566 (63)	1.3% (1.1)
Adults							
	HFA	756 (119)	658 (105)	3.6% (3.1)	693 (99)	638 (88)	2.0% (1.0)
	TD	538 (85)	507 (79)	1.4% (1.2)	581 (93)	530 (100)	2.5% (1.9)

Cells contain mean scores and (SD). Interference computed as (inconsistent–consistent) as a percentage of total reaction time. Global interference reflects the influence of local processing and local interference reflects the influence of global processing.

right index finger to indicate their response. The order of the blocks was randomized for each participant. Participants executed the task in a dimly lit room at a viewing distance of approximately 60 cm from the screen.

Data Analyses

Mean RTs for each participant were submitted to a log transformation to establish homogeneity of variance prior to being submitted to the analyses. Only correct trials were analyzed for RT differences across the experimental conditions. Analyses and figures of error data are provided in the Supplementary Materials online.

Results

Table II shows the mean RT and the amount of interference in each condition as a function of total RT for children, adolescents, and adults in each group.[1] In the adults, HFA adults responded more slowly than TD adults, $F(1, 16) = 11.8$, $P < 0.005$; however, there was a globality × experimental group interaction, $F(1, 16) = 11.7$, $P < 0.005$. TD adults were faster to identify letters at the global level, whereas HFA adults were faster to identify letters at the local level. There were no group differences in either the adolescents or children.[2] TD and HFA adolescents were equally fast to respond in general, $F(1, 28) = 0.3$, $P =$ n.s., and were both faster to identify letters at the local compared to the global level, $F(1, 28) = 6.0$, $P < 0.025$. For the children, there was only a main effect of consistency, $F(1, 28) = 13.7$, $P < 0.001$, and a trend for the HFA group to be slower than the TD group, $F(1, 28) = 3.5$, $P = 0.07$.

Additionally, a composite measure of the global advantage was computed for each participant [(local inconsistent–local consistent)–(global inconsistent–global consistent)] and submitted to a regression with age, separately for the TD and HFA groups. Higher scores indicate a larger global advantage and scores less than zero represent a local bias. As evident in Figure 2, in the TD group, there was a significant effect of age, $F(1, 38) = 7.3$, $P < 0.01$, slope = 3.43, indicating that with increasing age, there is a concomitant increase in global advantage (Fig. 2a). However, in the HFA group (Fig. 2b), there was no significant effect of age, $F(1, 38) = 1.1$, $P =$ n.s., even when the two children with extremely high global advantage scores and the one adult with a disproportionately stronger local bias were taken out of the analysis, $F(1, 34) = 0.8$, $P =$ n.s., indicating no age-related increase in the bias to encode the global shape of these hierarchical stimuli.[3]. It is also important to note that the group differences in age-related changes in global advantage were not related to differences in overall RT. Faster RTs were not correlated with higher global advantage scores in either the typical, $r(39) = -0.25$, $P =$ n.s., or the autism, $r(39) = -0.07$, $P =$ n.s., groups.

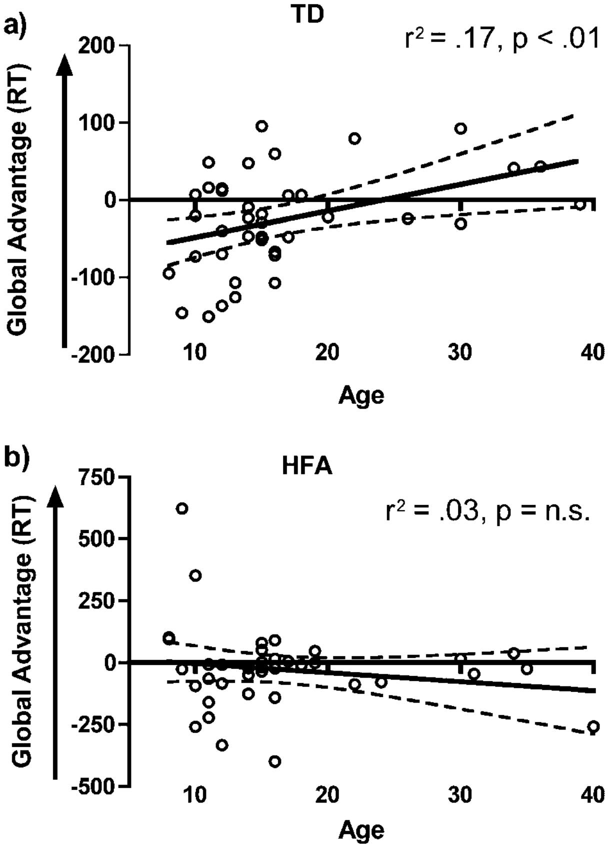

Figure 2. Global advantage in reaction time (RT) [(local inconsistent–local consistent)–(global inconsistent–global consistent)] plotted as a function of age with 95% confidence intervals for typically developing (TD) (*a*) and high-functioning autistic (HFA) (*b*) individuals. To maximize the illustration of each group's performance, the global advantage scores in the TD and HFA groups are plotted on different scales. The global advantage in RT significantly increased with age only for the TD group.

The error analyses were generally consistent with the RT findings. Briefly, there were no significant interactions between group and globality in any of the

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[1] Levene's Tests for Equality of Variances were conducted on the mean log transformed RT scores (collapsed across condition) within each age group. HFA and TD children and adults showed similar amounts of variance ($F < 1$); however, the HFA adolescents tended to have more variance in RT than did the TD adolescents, $F(1, 28) = 3.2$, $P = 0.08$.

[2] Tthe developmental differences in sensitivity to global information are not likely to be related to the uneven distribution of females across the age groups. The TD results were previously published and included developmental analyses with and without the female participants, which produced the exact same pattern of results [Scherf et al., 2008]. Also, two recent studies with TD adults using similar tasks failed to find gender differences [Kimchi et al., in preparation; Müller-Oehring, Schule, Raassi, Pfefferbaum, & Sullivan, 2007]. This convergence of results suggests that sex differences are not likely to influence developmental biases in global and local processing.

[3] The global advantage scores were computed on the raw RT scores for these analyses. The scores were also computed on the log transformed RT scores and analyses of these data produced the same results.

within-age-group analyses. This indicates that at each developmental stage, the TD and HFA groups were *similarly accurate across conditions*. Although HFA children were less accurate than TD children, both groups were less accurate on inconsistent trials. Error was only a sensitive measure for processing bias in the adolescents. Both TD and HFA adolescents showed the classic local processing bias.

Discussion

The goal of this study was to evaluate the developmental trajectory of visuoperceptual processing in autism, with particular emphasis on the development of global processing. In the TD group, sensitivity to global information increased linearly with age. We found no evidence of global precedence in the visual representations of individuals with autism in any age group. Furthermore, the local processing bias only began to emerge in adolescence and did not stabilize until adulthood in autism. HFA children showed no clear processing biases and were disproportionately slower when the stimuli contained inconsistent information, regardless of the level at which they were identifying the letters. This finding is consistent with the claim that HFA children have impairments in executive control processes that guide attention to either the global or local level of information in a visual stimulus [Iarocci et al., 2006; Plaisted et al., 1999].

Our findings of atypical global processing in autism are consistent with one study using a similar task with HFA and TD adults [Rondan & Deruelle, 2007] and another with adolescents [Wang et al., 2007]. Unlike the previous studies that reported evidence of a typical global advantage in HFA individuals under certain stimulus conditions (e.g., selective attention version of the task), we did not observe this pattern.

It is already known that in adults, many parameters affect the global advantage [see Kimchi, 1992], including the length of the exposure duration and the spacing between and the number of local elements, and are especially relevant to differences in the developmental findings. In some adult studies, asymmetrical global-to-local interference has only been observed under very short exposure durations [Paquet & Merikle, 1984] and when there are many local elements close together that generate good exemplars of the global figure [Kimchi, 1998; Martin, 1979; Navon, 1983]. In the current study, participants were given an unlimited stimulus exposure duration even though several of the previous developmental studies used a limited duration [Ozonoff et al., 1994; Plaisted et al., 1999]. The unlimited exposure duration may have resulted in behavioral responses that are more reflective of the final percept and not a temporally early processing bias. Also, previous experiments reporting a global advantage effect in children often used a stimulus that contained many (56) small, densely packed local letters [Ozonoff et al., 1994; Plaisted et al., 1999], which were organized in clusters (e.g., the base of a large "S" was composed of a cluster of four small "Hs"). In contrast, our stimuli included a global letter made from either 12 (H) or 14 (S) more sparse local letters that did not cluster into smaller subsections of the global letter. All of the local letters in these stimuli must be integrated to identify the shape of the global letter. TD and HFA children in the previous studies exhibiting faster identification times for the global letter may have been doing so based on element clustering of these smaller subsections of the global letter. As mentioned previously, element clustering appears to develop fairly early in typical children, whereas shape formation develops into late adolescence [Kimchi et al., 2005; Scherf et al., 2008]. This interpretation suggests that element clustering abilities may be spared in autism and develop in a typical manner.

One potential resolution of the discrepancy between our findings and those of previous studies is that perceptual organization involves multiple processes that vary in developmental trajectories, some of which may be spared in autism as others are impaired. At least two studies have found evidence that the developmental trajectories of perceptual grouping abilities for displays with many, small element items differ compared to those with few large elements in TD populations [Kimchi et al., 2005; Scherf et al., 2008] and this ability may be somewhat spared in autism.

Study 2: Microgenetic Analysis of the Perceptual Organization of Hierarchical Stimuli

In the next experiment, we evaluated whether individuals with autism exhibit an early bias to encode the global shape of a hierarchical stimulus, but find the local elements more salient and dominant in their final percept, and whether they show more of a global advantage in response to many-element stimuli using a dynamic method in which the representation can be probed during its process of temporal evolution. This is particularly relevant in order to uncover whether some global information is available at all during the formation of the percept, particularly in adolescents with autism.

We adopted a paradigm developed by Kimchi [1998, Experiment 1] to test perceptual organization processes in typical adults. Here, participants view (but ignore) an ambiguous prime followed immediately by a pair of test figures (probes) and judge whether the two probes are same or different. The prime and probe stimuli include patterns (i.e., global diamond composed of smaller circles) with few large elements or with many small elements. Probe displays include a pair of stimuli, drawn from one of the two conditions, and defined by their similarity to the prime stimulus (see Fig. 1b). In the *element-similarity* (ES) condition, probes are similar to the prime in their local elements (circles), but differ in their global configuration (global square instead of global diamond). In the *configuration-similarity* (CS) condition, probes are similar to the prime in their global configuration (diamond), but differ in their local elements (local squares instead of local circles). The prime is presented at several durations, providing multiple temporal windows over which the representation evolves prior to the onset of the probe stimuli, and behavioral responses to the probe displays are compared across these prime durations.

At short prime durations, the most dominant characteristic of the percept of the priming stimulus is represented. When the probe displays share these entry-level characteristics with the prime, responses will be facilitated. At longer prime durations, both local and global characteristics may be represented in which case the prime would enhance both of these dimensions in responses to the probe figures. Of particular importance, for TD adults, global shape information is encoded in the entry-level units of the representation for the many-element displays, indicating the global shape advantage [Kimchi, 1998]. This provides us with a sensitive way in which to assay the presence of global stimulus structure in the entry-level units of percepts in children and adolescents with autism. Thus, while the few-element task (FET) reveals abilities to perceptually individuate local elements, the many-element task (MET) uncovers the rapid formation of a global percept even at brief exposure durations.

Methods

Participants

The participants in this study included the same individuals as in the previous study.

Design and Procedure

In a single block, only few- or many-element items were presented. The global shapes of the few- and many-element global figures were matched for size even though they differed in terms of the number and the size of local elements (see Fig. 1b). The few-element prime consisted of a global diamond made of four large circles, which subtended 0.36° in diameter. The local squares in the few-element probe stimuli subtended 0.38° in diameter. The many-element prime was a global diamond made of 16 small circles, which subtended 0.18° in diameter. The local squares in the many-element probe stimuli subtended 0.19° in diameter. The global diamond subtended 1.25° of visual angle and the global square 0.96°. There was a distance of 7 cm between the centers of the two probe test stimuli.

There were 160 trials, preceded by 16 practice trials, in two blocks (320 trials). Prior to testing in each task, participants verbally identified the "big" shape and the "little" shape in a probe stimulus. Each trial began with a small fixation dot that appeared in the center of the screen for 250 msec, followed by a prime that appeared for 40, 90, 190, 390, or 690 msec. A probe test pair appeared immediately after the prime on either side of the location previously occupied by the prime and stayed on the screen until the participant responded or until a maximum of 3,000 msec. Participants had to decide whether the probes in the test pair were "exactly the same" or "different in any way." They were instructed to respond "as quickly as possible without making mistakes" with their left index finger on the "s" key if the items were identical or on the "d" key with their right index finger if the items were different.[4] All combinations of the three factors (prime duration, condition, and response) were randomized within a block and occurred equally often.

Data Analyses

RT responses were only evaluated for correct *same* trials since the relationship between the prime and the test pair is clearly known. On different trials, the probe stimuli differ from the prime both in the elemental and configural information; hence, it is impossible to know what aspect of the probe pair participants attend to when making a different judgment. Also, previous studies using similar paradigms in adults have only found priming effects for *same* responses and have failed to find priming effects for *different* responses [Beller, 1971; Kimchi, 1998]. Responses from the two tasks were analyzed separately since the few-element and many-element displays elicit different kinds of grouping and individuation processes [Kimchi et al., 2005]. Levene's Tests for Equality of Variances on the mean log transformed RT scores (collapsed across condition) within each age group for each task revealed that in the FET there were similar amounts of variance in the TD and HFA individuals in each age group ($F<1$). In the MET, only HFA adolescents exhibited more variance than did the TD adolescents, $F(1, 28) = 5.9$, $P<0.025$. See Supplementary Materials online for analyses and figures of error data.

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[4] We did not counterbalance the mapping of the finger to the letter since the "s" is to the left of the "d" on the keyboard and crossing the fingers to make a response would have been very awkward. In preliminary analyses, TD and HFA children and adolescents were faster to make "same" responses in both the few and many tasks, even with their left index finger, which is consistent with previous findings that same judgments are easier to make [Nickerson, 1965]. Importantly, this pattern of responding was not different across groups; there were no group × response interactions.

Results

Few-elements task: Figure 3 shows the mean RT for the few-element displays for children (a, b), adolescents (c, d), and adults (e, f) in both groups. HFA adults were slower to respond than TD adults, $F(1, 16) = 5.7$, $P<0.05$, and both HFA and TD adults judged probes consistently faster in the ES compared to CS condition, $F(1, 16) = 16.5$, $P<0.001$. However, these main effects need to be considered in the context of the condition × group interaction, $F(1, 16) = 5.3$, $P<0.05$. TD adults showed a 105 msec advantage for ES compared to CS items, which was more than twice the advantage exhibited by the HFA adults at 45 msec. Similarly, in the adolescent group, HFA

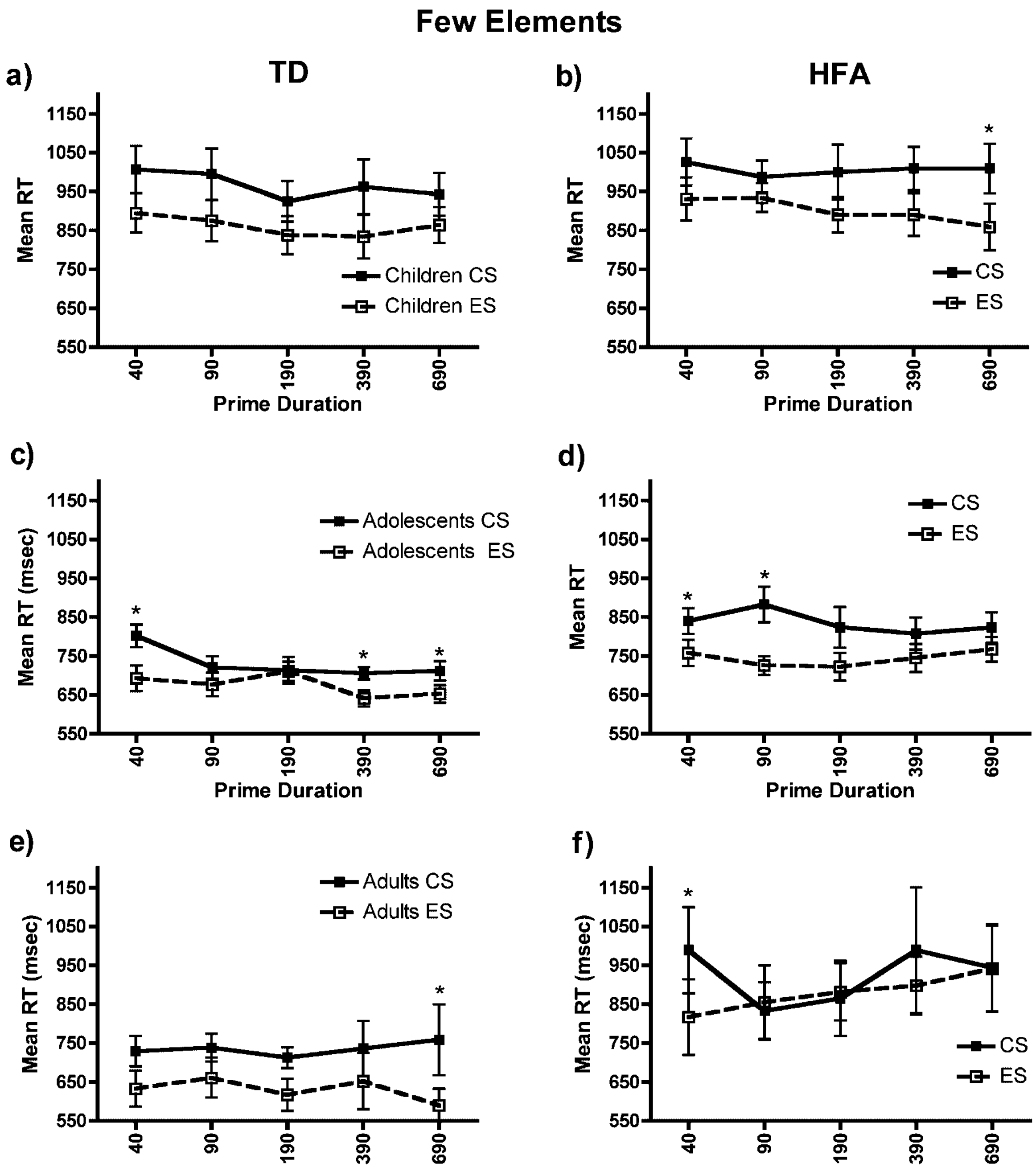

Figure 3. Reaction time (RT) results for few-element task. Mean RT ± 1 SEM separately for children (***a***, ***b***), adolescents (***c***, ***d***), and adults (***e***, ***f***). All groups were faster to identify the local elements (ES) compared to the global configuration (CS) in the few-element displays. *$P<0.05$ as determined by Tukey HSD post hoc comparisons within each age group when a condition × prime duration × experimental group interaction was present. ES, element similarity; CS, configuration similarity; HSD, honestly significant difference; TD, typically developing; HFA, high functioning individuals with autism.

participants were slower to respond than were TD individuals, $F(1, 28) = 5.3$, $P < 0.05$; however, both HFA and TD participants judged probes faster in the ES than CS condition, $F(1, 28) = 32.2$, $P < 0.001$ (mean 64 msec ES advantage). Finally, both HFA and TD children responded equally quickly, $F(1, 28) = 0.5$, $P =$ n.s., and judged probes faster in the ES than CS condition, $F(1, 28) = 50.4$, $P < 0.001$ (mean 105 msec ES advantage).

Results from the error analyses produced a similar pattern of results. Briefly, children and adolescents in both the TD and HFA groups were more accurate when judging ES compared to CS items across all prime durations. TD and HFA adults were equally accurate in both conditions. Interestingly, TD adolescents tended to perform less accurately than did HFA adolescents, perhaps reflecting the instability of the growing global bias under these conditions, which typically elicit a local bias.

To summarize, children, adolescents, and adults in both groups were biased to encode the local elements of the few-element displays, regardless of the prime duration, indicating that the ability to individuate elements presented in hierarchical displays with few, large items matures quite early in both TD and HFA populations. However, the HFA adults exhibited a weaker sensitivity to the local elements than did the TD adults, indicating that they do not evince superior processing of the local information when the elements are few and large.

Many-elements task: Figure 4 shows the mean RT for the many-element displays for children (a, b), adolescents (c, d), and adults (e, f) in both groups. Among the adults, HFA individuals tended to respond more slowly than TD individuals, $F(1, 16) = 4.4$, $P = < 0.052$. More importantly, there was a main effect of condition, $F(1, 16) = 14.3$, $P < 0.005$, and significant condition × group, $F(1, 16) = 5.3$, $P < 0.05$, and condition × prime × group, $F(4, 64) = 2.9$, $P < 0.05$, interactions. Although both groups were generally faster to judge probe items in the ES condition, the ES advantage for HFA adults (151 msec) was more than three times that of the TD adults (44 msec). Furthermore, TD adults were only faster to judge ES than CS items at the 190 msec prime duration, indicating that global information is more strongly represented early in the formation of the percept and in the final percept. HFA adults were faster to judge ES items across the range of prime durations (90, 190, and 690 msec), which indicates that in HFA adults, local information dominates the formation of the percept from the initial encoding to the organization of the final percept, when the local elements are many and small.

Similarly, among the adolescents, HFA and TD individuals responded equally quickly throughout the task, $F(1, 28) = 1.9$, $P =$ n.s. There was a main effect of condition, $F(1, 28) = 19.9$, $P < 0.001$, and a condition × prime × group interaction, $F(4, 112) = 3.9$, $P < 0.005$. Although both groups were faster to judge probe items in the ES condition, the ES advantage for the HFA adolescents (84 msec) was more than twice that of the TD adolescents (36 msec). HFA adolescents were faster to judge ES items at the 40 and 90 msec prime durations, $P < 0.05$, whereas TD adolescents were not significantly faster to judge ES items at any prime duration, perhaps reflecting the onset of a global advantage and growing reduction of the ES advantage.

Finally, among the children, HFA and TD individuals responded equally quickly throughout the task, $F(1, 28) = 0.1$, $P =$ n.s. There was a main effect of condition, $F(1, 28) = 19.1$, $P < 0.001$, and significant condition × group, $F(1, 28) = 6.7$, $P < 0.025$, and condition × prime × group, $F(4, 112) = 4.0$, $P < 0.005$, interactions. Although both groups were faster to judge probe items in the ES condition, the ES advantage for the HFA children (135 msec) was more than four times that of the TD children (31 msec). HFA children were faster to judge ES items at the 40, 390, and 690 msec prime durations, $P < 0.05$. TD children were only faster to judge ES items at the 190 msec prime duration, $P < 0.05$.

The within-age-group analyses indicate that there are impressive group differences in the developmental trajectories for sensitivity to global information in the MET. To evaluate these differences directly, mean RT differences scores (CS−ES) were computed for all six groups at each prime duration (see Fig. 5). A repeated-measures analysis of variance (ANOVA) on this difference score with the factors of experimental group, age group, and prime duration revealed a significant main effect of experimental group, $F(1, 72) = 20.4$, $P < 0.001$, indicating that the HFA group showed larger biases across all prime durations than did the TD group. Importantly, there was also a significant prime duration × age group × experimental group interaction, $F(8, 228) = 4.6$, $P < 0.001$. Separate ANOVAs within each experimental group revealed that there were age group × prime duration interactions in both the TD, $F(8, 144) = 4.3$, $P < 0.001$, and HFA, $F(8, 144) = 2.4$, $P < 0.025$, groups. However, the pattern of age-related changes was quite different across the groups.

In the TD group, separate one-way ANOVAs performed at each prime duration showed significant age group differences at the 40 msec, $F(2, 38) = 4.0$, $P < 0.05$, 190 msec, $F(2, 38) = 5.9$, $P < 0.01$, and 690 msec, $F(2, 38) = 3.2$, $P < 0.05$, prime durations. Bonferroni-corrected post hoc comparisons revealed that TD children showed a stronger element bias (i.e., shorter RTs in the ES condition) than TD adults at the 40 msec, $P < 0.05$, and 190 msec, $P < 0.01$, prime durations. TD children tended to show more of an element bias than TD adolescents at the 190 msec prime duration, $P = 0.074$. None of the TD groups differed at the 690 msec duration. Contrary to the TD group, in the HFA group there was no significant age-related change at the 40 msec prime duration, $F(2,$

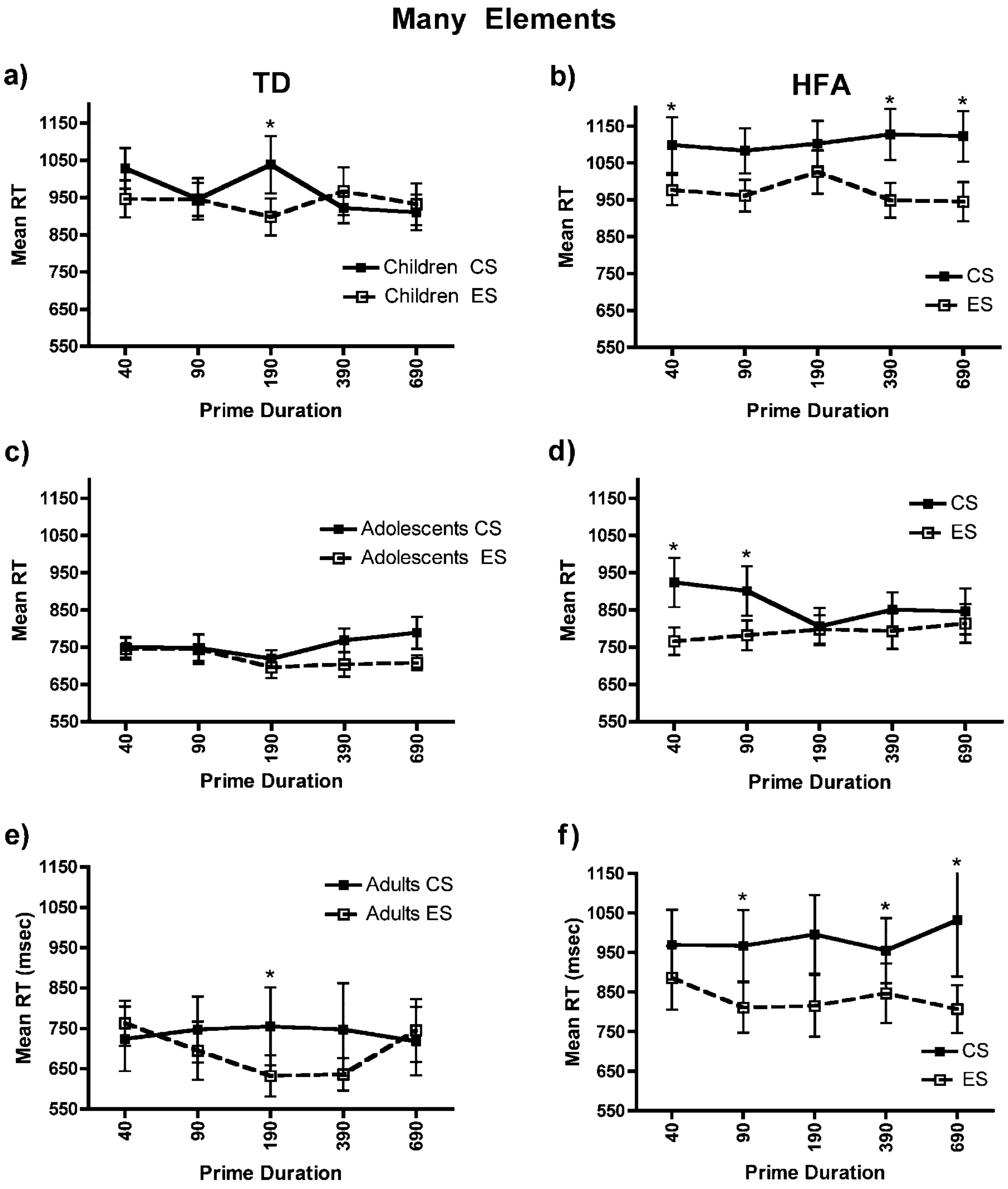

Figure 4. Reaction time (RT) results for many-element task. Mean RT$\pm$1 SEM separately for children (*a*, *b*), adolescents (*c*, *d*), and adults (*e*, *f*). Typical adults showed an early advantage for the global configuration (CS) compared to the elemental information (ES) at the 40 msec prime duration. No other group demonstrated this advantage. In fact, both TD and HFA children and adolescents and HFA adults showed an element advantage, which was more prominent in the HFA participants. $^*P<0.05$ as determined by Tukey HSD post hoc comparisons within each age group when a condition $\times$ prime duration $\times$ experimental group interaction was present. CS, configuration similarity; ES, element similarity; TD, typically developing; HFA, high-functioning individuals with autism; HSD, honestly significant difference.

38) = 1.4, P = n.s. There were statistical trends for age-related changes at the 190 msec, $F(2, 38) = 2.9$, $P = 0.07$, and 690 msec, $F(2, 38) = 2.7$, $P = 0.08$, prime durations. Interestingly, HFA adults tended to show a larger element bias than did the HFA adolescents at the 190 msec, $P = 0.062$, and 690 msec, $P = 0.08$, prime durations. This indicates that, as in the global/local (GL) task with the compound letter stimuli, the HFA individuals do not

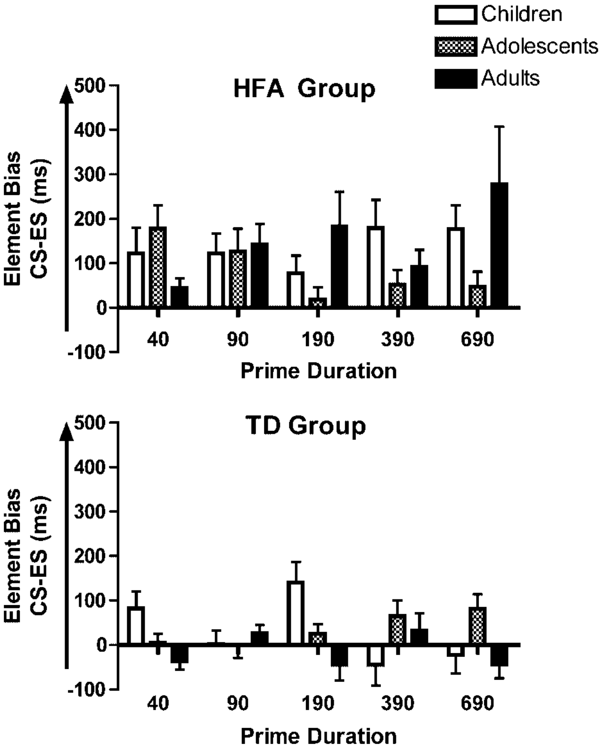

Figure 5. Summary of developmental differences between the HFA and TD groups in many-element reaction time results, plotted as a function of element bias (configural similarity–element similarity) for each age group. HFA, high-functioning individuals with autism; TD, typically developing.

show an age-related increase in sensitivity to the global properties of the many-element stimuli, and there is some evidence that they may become *more* biased to encode the local elements with age during the formation of the initial percept and the longer-term representation.

Despite the impressive age and diagnostic group differences in RT on the many-element task, there were no such differences in accuracy.

Discussion

Using the microgenetic prime paradigm (MPP), we found that HFA and TD participants in all three age groups were biased to encode the local elements of the few-element displays. We did not find evidence of superior local processing in autism for any age group in the few-element task (FET). In fact, TD adults showed a much larger advantage in the similar element compared to the similar configuration condition than did the HFA adults. These findings may help reconcile previous studies that have failed to find group differences in perceptual organization processes in autism. If the local elements are few and large, both TD and HFA groups are strongly biased to individuate these displays even in childhood and perceptual individuation abilities are not apparently superior in autism. Results from the many-element task (MET) are more revealing about developmental atypicalities in perceptual organization abilities in autism. HFA children, adolescents, and adults were all strongly biased to individuate the many-element displays across the range of prime durations, whereas the TD group evinced an age-related decline in this tendency and an increase in sensitivity to the global shape information with age.

Taken together, these findings suggest that, beginning in childhood, local information dominates the formation of a percept in autism from the entry-level units to the longer-term visual representation, regardless of the stimulus characteristics of the local elements. This developmental pattern is inconsistent with that of TD individuals, who show a gradual transition to a global processing bias beginning in adolescence, particularly for displays with many small elements. Also, we found evidence of superior processing of the local elements in autism for all age groups in the MET, particularly at the short prime durations, when the global configuration is so strongly represented in typical adults [Kimchi, 1998]. Individuation of these local elements is time consuming and requires focused attention in typical adults, but it appears to be fairly automatic in autism, even in childhood.

The developmental differences between the HFA and TD groups are not obviously attributable to the differences in the variability of performance among the adult groups. Although there were only nine adults in each group, this subset of adults taken from the larger study [Behrmann et al., 2006] exhibit the same pattern of group differences as the full sample. Also, there was an equal amount of variance in the adult groups in each task at each prime duration.

These findings are somewhat at odds with those of Plaisted et al. [2006] who failed to find group differences between HFA and TD children (10 years old) in a delayed matching version of the MPP. However, our results suggest that even in childhood, there are differences in the magnitude of the local processing bias, which are particularly evident when encoding displays with many small elements. Furthermore, individuals with autism do not transition to a global processing bias that appears to begin in adolescence in TD individuals [Scherf et al., [73]2008].

General Discussion

The goal of these studies was to investigate the development of visuoperceptual organization in autism from late childhood through early adulthood. In particular, we focused on evaluating developmental changes in the ability to group local elements in the service of perceiving the global shape of an object. Given the evidence of a strong bias to process local information in adults with autism, we were especially interested in understanding (1) when this local processing bias emerges both developmentally and over the course of a single trial as a function of age of the observer, (2) whether the bias is pervasive across several kinds of hierarchical stimuli, and (3) whether and to what extent such a bias interferes with the perception of the global shape of these stimuli. We investigated sensitivity to global and local information in hierarchical visual displays in individuals across a wide age range using compound letter stimuli [Navon, 1977] and using a microgenetic (MPP) approach to map the evolution of both the local and global aspects of the visual representation [Kimchi, 1998]. Our results suggest that there is, in fact, atypical development of the ability to integrate local elements into a global shape, which is primarily evident when individuals with autism process hierarchical forms with many small elements, and which becomes especially apparent in adolescence when the global advantage is emerging in TD individuals.

In our first task of GL processing with letter stimuli, only TD adults exhibited the classic pattern of global advantage, with faster identification of the global than the local letters. These results suggest that the development of a global advantage follows a long developmental trajectory into adulthood in TD individuals, which is consistent with several other findings of a protracted developmental trajectory for the ability to integrate local visual features across the visual field [Kovacs, 2000; Kovacs et al., 1999; Kozma, Kovacs, & Benedek, 2001]. We found no evidence for the development of such a global advantage in the HFA group. In fact, in this task, there was no clear pattern of perceptual bias in the HFA children, whose performance was substantially disrupted whenever inconsistent stimuli were presented. Furthermore, the local advantage did not emerge as a perceptual bias until adolescence in the HFA group, and did not stabilize until adulthood. Our findings indicate that the transition from adolescence to adulthood in autism is marked by a failure to develop the global shape advantage that begins to emerge in adolescence in TD individuals. Finally, we did not find evidence of enhanced processing of the local elements in the HFA group until adulthood, when the HFA participants exhibited a local advantage and the TD adults exhibited a global advantage.

Our findings from the GL task appear to be consistent with the WCC account of perceptual processing, which suggests that there is a fundamental impairment in the perception of global information in autism. However, results from the more novel MPP are consistent with the hypothesis that some processes involved in perceptual organization are spared in autism, whereas others are impaired. For HFA individuals, the ability to individuate local elements when presented in the context of a group develops early, as in TD populations, and remains a strong bias in adulthood. However, the ability to group local elements perceptually in order to perceive a global shape never matures during the developmental transition from adolescence to adulthood as it does in TD individuals. It is important to note that these findings are not likely to be attributable to age-related differences in task-specific skills, such as letter recognition and directed attention, since a similar pattern of group differences was observed in both the Navon and many-element tasks despite their differences.

This is not to say that HFA children and adolescents are insensitive to global shape information. In fact, they were both highly accurate when identifying the global letter in the compound letter stimuli and when making similarity judgments about stimuli that shared a global configuration in the MPP. However, the much slower RTs in response to the global information in both experiments for all three HFA age groups indicate that the holistic entity is much more weakly represented than is the local information, particularly when processing displays with many small elements.

WCC or Enhanced Perceptual Functioning?

Contrary to the predictions of the EPF framework, we did not find evidence for pervasive superior processing of local details across ages and tasks in the individuals with autism. For example, the local processing advantage is not developmentally different from TD individuals when it comes to processing hierarchical displays with a few large elements. Also, contrary to the predictions of the WCC framework, even though children, adolescents, and adults with autism were much slower to identify global information in several kinds of hierarchical displays, they were all highly accurate when explicitly identifying or discriminating stimuli based on global information. This suggests that neither the WCC nor the EPF frameworks, as stated, can explain the pattern of results that we have reported. Our results suggest that atypicalities in perceptual organization in autism are dependent on the developmental stage, the characteristics of the hierarchical displays, and, thus, the nature of the perceptual organizational processes that are engaged.

Across these two experiments, our stimuli engaged perceptual individuation (FET), element clustering (GL and MET), and global shape formation processes (GL and MET). First, across all ages tested, the HFA group exhibited similar perceptual individuation abilities in the FET as did the TD group. Second, the HFA group was highly accurate, but disproportionately slower, at processing global information in the compound letter stimuli and the many-element stimuli, which only began to be apparent in adolescence. In both of these tasks, a precise representation of the local relations must be derived to identify the global letter or to facilitate responses to the probe stimuli that share the global shape with the prime. One possible reconciliation for the highly accurate but relatively slower processing of global information, particularly in the MET, in the HFA group is that even in childhood, individuals with autism are capable of grouping many small elements to a certain degree, which may support some global information. For example, element clustering, which involves determining which elements belong together, may be spared in autism and may have enabled the extraction of sufficient configural information to support fairly accurate performance in these tasks. However, the disproportionately slower RTs in response to global information in the HFA group and the failure to exhibit increasing sensitivity to global information with age indicate that the full process of garnering *precise shape information* from perceptual grouping never appears to mature in autism.

Limitations and Future Directions

The participants for this study all met research criteria for high-functioning autism. Previous neuropsychological research in autism has shown that impairments are often most pronounced in subjects diagnosed with autism and less severe or not detectable in those with Asperger's disorder or pervasive developmental disorder, not otherwise specified (PDDNOS). The restriction of this ASD sample to those with high-functioning autism has the advantage of greater uniformity, but also means that the findings cannot be generalized to individuals with Asperger's disorder or PDDNOS. A second limitation involves our use of a cross-sectional design to investigate developmental trajectories. Replications using longitudinal designs will be essential for understanding more about adolescence as a vulnerable developmental period in autism. Finally, the lack of IQ data on the typical adult group is a minor weakness, offset somewhat by the normal IQs of the HFA group and pattern of responses in the TD adults, which is consistent with previous studies using the same tasks.

Conclusions

In conclusion, our results suggest that perceptual organization processes in HFA and TD individuals diverge developmentally in *adolescence* with HFA individuals failing to acquire mature global shape perception. This developmental deficit in perceptual organization processes may be related to limitations in the development of higher-order face and object processing that are so widely reported in autism and that rely heavily on global shape perception [Joseph & Tanaka, 2003; Klin et al., 2002; Lahaie et al., 2006]. One study reported an association between impairments in global shape perception in the GL and MPP tasks and in face discrimination abilities in adults with autism [Behrmann et al., 2006]. Our finding that adolescence is a particularly vulnerable developmental period in autism for global shape perception is important in light of the findings that this is a critical time for the functional and structural development of the ventral visual stream, which is implicated in object form, shape, and identity coding [Bachevalier, Hagger, & Mishkin, 1991; Barnea-Goraly et al., 2005; Gogtay et al., 2004; Scherf, Behrmann, Humphreys, & Luna, 2007] and appears to be abnormal in children and adolescents [Grelotti, Gauthier, & Schultz, 2002; Wang, Dapretto, Hariri, Sigman, & Bookheimer, 2004] and adults with ASD [Ashwin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, 2007; Bailey, Braeutigam, Jousmaki, & Swithenby, 2005; Humphreys, Hasson, Avidan, Minshew, & Behrmann, 2008; Pierce, Muller, Ambrose, Allen, & Courchesne, 2001; Schultz et al., 2003]. These neural differences may be present throughout development in HFA individuals and might serve as the basis for the atypical maturation of perceptual organization and the failure to develop mature global shape processing in adolescence.

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