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ORIGINAL PAPER

A Developmental Perspective of Global and Local Visual Perception in Autism Spectrum Disorder

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Abstract Individuals with autism spectrum disorder (ASD) demonstrate superior performances on visuo-spatial tasks emphasizing local information processing; however, findings from studies involving hierarchical stimuli are inconsistent. Wide age ranges and group means complicate their interpretability. Children and adolescents with and without ASD completed a Navon task wherein they identified global and local stimuli composed of either consistent or inconsistent letters. Trajectories of reaction time in global and local conditions were similar within and between groups when consistent and inconsistent stimuli were considered together, but the effect of local-to-global interference was significantly higher in participants with than without ASD. Age was not a significant predictor of local-to-global interference, suggesting that this effect emerges in childhood and persists throughout adolescence in ASD.

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Introduction

Global and local processing are two of the most extensively researched aspects of visual perception in autism spectrum disorder (ASD). One reason for this is frequent reports of superior local performances in these individuals. Many studies have shown that individuals with ASD outperform typically developing (TD) individuals in visuo-spatial tasks, and this performance can be attributed to the optimal use of a local strategy (see Simmons et al. 2009 for a review). For example, individuals with ASD are often faster and better at identifying target stimuli in visual search tasks (Joseph et al. 2009; O'Riordan et al. 2001; O'Riordan 2004; Plaisted et al. 1998), segmenting and constructing patterns in the Block Design task (Caron et al. 2006; Shah and Frith 1993), and locating shapes in the Embedded Figures task (Jolliffe and Baron-Cohen 1997; Shah and Frith 1983). Taken together, these reports of superior performances suggest a bias towards local processing in individuals with ASD (Mottron and Burack 2001; Mottron et al. 2006).

It is important to note, however, that individuals with ASD do not show an enhanced performance on *all* visuo-spatial tasks (reviewed in Happé and Booth 2008). Some studies reveal that individuals with ASD perform poorer than TD individuals in tasks requiring a global analysis, whereas others demonstrate that they perform comparably. These inconsistencies suggest that perception in ASD cannot be characterized simply in terms of increased local or decreased global processing, but rather, as a complex interplay between them.

Two main theories have been proposed to characterize and explain these differences in global and local processing: the weak central coherence theory (WCC; Frith and Happé 1994; Happé and Frith 2006) and the enhanced perceptual functioning model (EPF; Mottron and Burack 2001; Mottron et al. 2006). The WCC relates to the concept of integrating component parts into a coherent whole. This theory proposes that individuals with ASD have a deficit in the higher-order processes governing such integration, causing them to process items as separate components rather than a unified whole. The reduced "top-down" influences therefore account for respective better and poorer performances in tasks necessitating a local and global analysis in ASD. More recent revisions to this theory, however, relinquish the notion of a global deficit, and instead intimate a local preference or processing style that can be overcome with explicit instructions. The EPF model alternatively focuses on perception and thereby, "bottom-up" processes. This theory proposes that an enhanced and increased autonomy of perception promotes local processing in ASD. The EPF suggests then that the superior performances seen in individuals with ASD on the visuo-spatial tasks mentioned above relate to enhanced perception and not a deficit in global processing.

While there are many visuo-spatial tasks that tap into global and local processes, the Navon task's versatility and adaptability (Navon 1977) have made it one of the most popular choices among studies in ASD as well as TD. One advantage of this task is the use of hierarchical stimuli in which larger "global" letters are composed of smaller "local" letters that are either *consistent* or *inconsistent*. Specifically, this means that the large and small letters are either the same or different. It is therefore possible to investigate both global and local processing in the presence or absence of conflicting information using the same stimuli. For example, one can examine the influence of inconsistent large letters on the detection of small letters (i.e., global-to-local interference) and inconsistent small letters on the detection of large letters (i.e., local-to-global interference).

The flexibility of its administration also adds to its popularity; the Navon task can be administered in a selective attention, divided attention, or free choice formats. The selective attention format includes a separate global and local condition wherein participants respond to the large and small letters, respectively. The divided attention format requires participants to respond to a specific stimulus, regardless of the level at which it is presented. The free-choice format presents participants with a hierarchical figure and then asks them to make a match from two choices, one of which shares the same local attribute and the other the global attribute. This latter format simply requires participants to perform a match based on what they see. Contrary to the selective and divided attention formats, the absence of explicit task instructions in the free-choice format is said to probe for spontaneous preferences rather than rule-based performance (e.g., Wang et al. 2007).

In line with its popularity, the Navon task has been used extensively in studies with TD individuals. The findings from these studies demonstrate that TD individuals detect global information more quickly than local information and show a perceptual bias for global information (Navon 1977; see Kimchi 1992 for review). This well-replicated finding is known as the global precedence effect (Robertson and Lamb; see Kimchi 1992 for a review), which includes both a global advantage (i.e., faster detection of global than local targets) and a global-to-local interference effect (i.e., slower detection of local targets in the presence of inconsistent global information).

Although the findings from studies conducted in TD individuals are generally consistent, those from similar studies in individuals with ASD have yielded mixed results (see Van der Hallen et al. 2014 for a review). For example, some studies using selective attention formats have found that individuals with ASD show a local advantage or increased local-to-global interference relative to TD individuals (Behrmann et al. 2006a; Rinehart et al. 2000; Wang et al. 2007), whereas others using the same type of administration have not (Hayward et al. 2012; Ozonoff et al. 1994; Plaisted et al. 1999). The same is true for studies using divided attention formats; while some have found that individuals with ASD detect local targets better than TD individuals (Plaisted et al. 1999), others have found a similar global advantage in both groups (Hayward et al. 2012; Mottron et al. 1999). Some studies have even shown that differences between TD and ASD groups may be influenced more by preferences rather than superior or inferior performances in the Navon task. For instance, Koldewyn et al. (2013) demonstrated that when given the choice, children with ASD showed a disinclination to report global information but were otherwise unimpaired in their ability to process such information.

The inconsistencies in these findings are partially attributable to methodological differences across studies. Previous reports have suggested that several task parameters, such as visual angle (Wang et al. 2007), density of small elements (Behrmann et al. 2006a), and type of administration (Koldewyn et al. 2013; Plaisted et al. 1999), can influence performance. As an example, Plaisted et al. (1999) found respective global and local precedence effects in the same participants with ASD using selective and divided attention formats of administration. A recent meta-analysis of visuo-spatial perception has reconciled some of these inconsistencies, demonstrating that global and local performances of TD and ASD groups are more similar than previously thought (Muth et al. 2014). The small effect sizes reported by Muth et al. (2014) suggest that there is only tentative evidence for a stronger global advantage in TD individuals in both the selective (median $d = .21$) and divided (median $d = .18$) attention formats of the Navon task. Moreover, individuals with ASD only show a small to medium preference for the local level of the Navon stimuli ($d = .35$).

The lack of well-defined developmental groups may also be responsible for the inconsistency in findings across studies in ASD. Participant groups often comprising children, adolescents, and adults contribute, at least in part, to the contradictory findings across studies of global and local perception in ASD. The use of wide participant samples ranging from childhood to adulthood relies on the presupposition that development has no effect on visual processing, and instead generalizes across age groups in ASD. This approach provides no information about the onset and rate of development of performance. A failure to do this is problematic, however, given the reported developmental differences in global and local perception in typical development.

Developmental studies in TD individuals have revealed important differences in the global and local processing of hierarchical stimuli (reviewed in Kimchi 2015). Findings from many of these studies suggest that local processing of hierarchical stimuli reaches adult-like levels earlier than global processing (Burack et al. 2000; Dukette and Stiles 1996; Harrison and Stiles 2009; Poirel et al. 2008; Porporino et al. 2004). However, this conclusion is not consistently supported by all developmental investigations. For example, some studies have found that global processing reaches adult-like levels by late childhood (e.g., Poirel et al. 2008; Porporino et al. 2004), whereas others have found that this occurs later in adolescence or adulthood (e.g., Scherf et al. 2009). Alternatively, some studies have reported a different developmental trend and suggest a more protracted development for local rather than global processing (e.g., Mondloch et al. 2003). Despite these inconsistencies, the literature generally supports the notion that visual perception transitions from a locally- to globally-based style in TD individuals. The mechanisms underlying this shift are not completely understood, though some suggest this may relate to a slow development of long-range neuronal connectivity supporting global shape integration (Kovács 2000).

Only one study has used the Navon task to examine developmental differences in global and local visual processes among individuals with ASD (Scherf et al. 2008). Scherf et al. (2008) compared the performances of children, adolescents, and adults with ASD to TD participants using a Navon task administered in a selective attention format. Their results revealed that children and adolescents with ASD responded similarly to their TD peers in terms of reaction times, but adults with ASD did not. Adults with ASD responded faster to local than to global letters, whereas typical adults responded faster to global than to local letters. Regression analyses also revealed that sensitivity to global information increased linearly with age in TD participants alone. The authors therefore concluded that for individuals with ASD, global perception may not develop to the same extent as in TD and that local perception may remain dominant in adulthood.

These findings above suggest that global and local perception develop atypically in ASD, but still, the grouping of participants into age bins is not ideal. This is because performances are averaged across arbitrary age ranges defined as child, adolescent, and adult. It is difficult to understand whether the youngest of oldest participants of a particular age group drive the reported effects. Moreover, it is challenging to interpret when exactly performances might change from one age group to another. Differences across age groups are therefore helpful in identifying a developmental trend but not necessarily the trajectory. As yet, the age-related changes of performances in the Navon task are unclear in ASD.

Scope of the Present Study

In the present study, a developmental trajectory approach was used to assess age-related changes in global and local visual perception in a large and well-defined group of participants with ASD. We had two main objectives, the first of which was to understand how global and local processes change as a function of age, without explicitly parsing the effects of interference. This was accomplished by constructing developmental trajectories of global and local performances collapsed across consistent and inconsistent stimuli. Using this approach, we considered age as a continuum rather than a criterion for grouping. Second, global and local interference was examined between groups using a novel approach that accounts for performance in the task without interference (i.e., consistent stimuli). Based on recent findings in school-aged children (Koldewyn et al. 2013) and across development (Scherf et al. 2008), it was expected that individuals with ASD would show a bias for local processing, reflected by faster or more accurate performance for local than for global stimuli, as well as local-to-global interference. We also predicted that these effects would increase with age.

Methods

Participants

Eighty-three participants between the ages of 6–16 years were tested in this study: 41 with ASD and 42 TD individuals. Two participants with ASD and two TD participants were excluded from the sample because of poor accuracy (i.e., <60 % correct responses) and results that strongly influenced the regression models for reaction time (i.e., large studentized and standardized residuals and DFBETAs). The final experimental group thus included 39 participants with ASD and 40 TD participants, and their data was included in all statistical analyses.

Participants included in the ASD group were recruited from a specialized hospital database. These individuals met criteria for ASD on the Autism Diagnostic Observation Scale (Lord et al. 2000) and/or the Autism Diagnostic Interview-Revised (Lord et al. 1994), as administered by an experienced clinician–researcher. Only participants with a diagnosis of autistic disorder (not Asperger's) based on the Diagnostic and Statistical Manual of Mental Disorders IV-TR (American Psychiatric Association 2000) were included. Typically developing participants were recruited from a participant database and within the community through local advertisements. Potential participants were excluded if they had a history of brain injury or neurological conditions, as indicated by their file history and clinical examination at time of assessment.

All participants were further screened using the Social Responsiveness Scale-Parent Form (SRS; Constantino and Gruber 2005). It is important to note that a number of parents spoke French as their first-language and were therefore provided with an in-house translation of this questionnaire. Many families requested to complete the forms at home and unfortunately, failed to return them. The questionnaires that were returned confirmed a low level of ASD traits in the TD sample (TD = 31 reports; ASD = 25 reports). TD participants, $M = 45.3$, $SD = 5.5$, obtained significantly lower scores than participants with ASD, $M = 73.2$, $SD = 13.9$; $t(29.9) = -9.45$, $p < .0001$. Although these results are consistent with expectations, the lack of validity, reliability, and specific norms for this unofficial translation warrants a cautious interpretation of its scores.

The general intellectual ability of all participants was assessed with either the Wechsler Abbreviated Scale of Intelligence (WASI-II; Wechsler 2011) or the Wechsler Intelligence Scale-Child version (WISC-III or IV; Wechsler 1991, 2003) in addition to the Raven Standard Progressive Matrices (RSPM; Raven et al. 1998). The single administration of the Wechsler Scales often underestimates intelligence in ASD and therefore, both the RSPM and WASI or WISC were administered (Barbeau et al. 2013; Dawson et al. 2007). Handedness was assessed with the Edinburgh Handedness Index (Oldfield 1971). All participants had normal or corrected-to-normal visual acuity (Lea Symbols Runge pocket card for near vision card and Snellen letter chart for far vision). Independent, *t* tests were conducted to examine differences in group means. These results, along with all other demographic information, are reported in Table 1.

The comparisons of group means indicated that age did not differ across groups, $t(77) = -.74$, $p = .46$, but full-scale IQ and verbal IQ scores did. The mean full-scale IQ scores were within the average range for both groups, but the TD group had significantly higher scores than the ASD group, $t(77) = 2.65$, $p = .01$. This difference is largely explained by the fact that the TD group also had significantly higher verbal IQ scores than the ASD group, $t(77) = 3.03$, $p = .004$. However, groups were matched on performance IQ and RSPM raw and percentile scores, which arguably, provide better indices of intellectual functioning in ASD (Barbeau et al. 2013; Dawson et al. 2007). No group differences were found for any other demographic information, all $p > .05$.

Verbal assent was obtained from all participants along with the written, informed consent of their parent or guardian. All families received a monetary reward for their participation. The study was approved by university and hospital ethics committees and conducted in accordance with the Declaration of Helsinki.

Stimuli

The stimuli were inspired by those previously used by Lamb and Robertson (1988), as well as Mottron et al. (1999) and Scherf et al. (2008). They consisted of four hierarchical letters wherein a large (global) letter was composed of small (local) versions of the same (consistent) or a different letter (inconsistent). Consistent stimuli included a large 'S' made of small 'S's or a large 'H' made of small 'H's, whereas inconsistent stimuli included a large 'S' made of small 'H's or a large 'H' made of small 'S's (see Fig. 1). The global and local letters subtended 3.2° × 2.3° and .53° × .44° of visual angle, respectively, when viewed from a distance of 57 cm. Black letters were presented on a white background. The presentation of stimuli varied spatially between trials from .5° to 2° of visual angle from the center of the screen to prevent anticipatory responses from participants maintaining their attention on one particular area of the screen or stimuli. The stimuli were created, controlled, and presented using VPixx© software (www.vpixx.com) on a MacPro G4

Table 1 Descriptive statistics for TD and ASD participant groups, including age (years), Wechsler's Intelligence Scale IQ (Full-Scale, Performance and Verbal) scores, Raven Standard Progressive Matrices scores (raw and percentile), and handedness

	TD (38 males, 2 females)			ASD (37 males, 2 females)			*p*
	Mean	*SD*	Range	Mean	*SD*	Range	
Age (years)	10.9	2.4	6–16	11.3	2.6	6–16	.46
Full-Scale IQ	107.5	15.3	84–151	98.3	14.6	73–134	.01*
Performance IQ	111.4	14.9	88–156	108.7	10.9	85–143	.42
Verbal IQ	108.7	16.4	85–160	96.8	16.1	55–123	.004*
RSPM (scores)	39.6	9.7	19–52	38.9	8.9	21–54	.74
RSPM (%ile)	71.8	18.2	40–99	68.8	25.7	9–99	.57
Handedness	38R/2L			34R/5L			

RSPM Raven Standard Progressive Matrices scores, *%ile* percentile

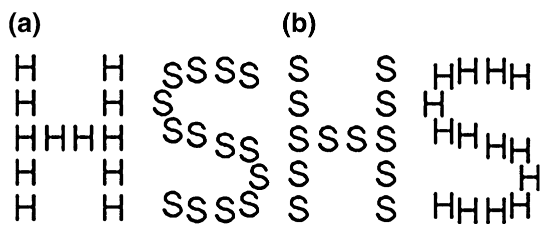

Fig. 1 Hierarchical stimuli used in the Navon task. The 'global level' was defined as the large letter, whereas the 'local level' was defined as the small letter. The letters were either **a** consistent or **b** inconsistent at the global and local levels

computer via a DataPixx™ video processing peripheral (16-bit video DAC). All stimuli were displayed on an 18-in. Viewsonic E90FB .25 CRT monitor with a pixel resolution of 1280 × 1024, and a refresh rate of 75 Hz.

No clear consensus exists over the definitions of the terms global and local, as these are conceptualized differently across studies (Happé and Booth 2008; Milne and Szczerbinski 2009). In this study, however, these terms refer to the hierarchical dimensions and size of the stimuli: the global level refers to the large letters, whereas the local level refers to the small letters. Moreover, "global" refers to the global property of the shape that accounts for the spatial relations among the smaller, local parts (Scherf et al. 2009).

Procedure

Participants completed a selective attention task consisting of separate global and local test blocks (i.e., conditions) in which attention was directed to either the global or local level, respectively. The simple nature of a selective attention format limited the necessary verbal instructions and overall task complexity, allowing us to test a wide age range of children and adolescents. Participants used a designated keyboard response to identify the global or local letter with their dominant hand. The importance of both speed and accuracy were emphasized in the instructions. Before each respective condition, participants completed 12 practice trials and received verbal feedback. Testing conditions consisted of 96 trials in which each of the four stimuli were presented 24 times in a random order. Trials began with the presentation of a fixation cross for a duration of 500 milliseconds (ms). This was then followed by the presentation of the stimulus (one of the four possible stimuli). The stimulus remained on the screen until a response was made or 10 seconds had elapsed. The order of global and local conditions was balanced across participants, with half of the participants completing the global trial first and the other half completing the local trial first. Measures of reaction time (RT) and accuracy were recorded.

Data Analysis

Separate analyses were used to examine reaction time (RT) and accuracy in global and local conditions. Cross-sectional, developmental trajectories were constructed for measures of global and local RT and accuracy using an adaptation of the method outlined in Thomas et al. (2009). Briefly, trajectories for overall global and local RT and accuracy in both the TD and ASD groups were used to determine if reliable linear relationships existed between task performance and age. Measures of RT and accuracy in both global and local conditions were collapsed across consistent and inconsistent stimuli to first examine global and local performance without considering the effects of stimulus consistency and thereby, interference. These trajectories were then compared within each group using a repeated-measures ANCOVA, with globality as a within-subjects factor and age as a covariate. Between-group differences were explored using a mixed-design ANCOVA with group as a between-subjects factor, globality as a within-subjects factor and age as a covariate. The groups were directly compared to determine whether the relationship between RT and age across global and local conditions was similar between groups. We examined whether performances in the TD and ASD groups varied at the earliest age of testing (intercept) and/or in their rate of development (interaction). Age was scaled in years from the youngest participants (i.e., 6 years) to facilitate comparisons of trajectories at their age of onset. These separate analyses were conducted to reduce the chance of masking effects within individual groups by the difference in variability between groups (e.g., Annaz et al. 2009; Leonard et al. 2010).

Standard multiple regression models were constructed in two steps to examine the effects of interference. In the first step, group and age-related differences in performance for consistent stimuli were considered. This was done to establish how the performance of the TD and ASD groups differed for consistent stimuli, which did not contain conflicting information and thus, no interference. These models included RT for consistent letters as a dependent variable, along with group and age as predictors. In the second step, the effects of interference were examined using a calculated difference score of interference (inconsistent RT–consistent RT) as a dependent variable and consistent RT, age, and group as predictors. Thus, global-to-local interference was analyzed using the difference in RT for inconsistent and consistent stimuli in the local condition as the dependent variable, while including RT for consistent stimuli in the local condition, age, and group as predictors in the model. Local-to-global interference was similarly assessed using the difference in RT for inconsistent and consistent stimuli in the global condition and RT for global consistent stimuli, age and group as predictors in the model. The RT for consistent letters was therefore considered the 'baseline' and the difference in RT for inconsistent and consistent letters, the measure of interference. A similar strategy was adopted to examine the effects of interference on accuracy using the following equations: (a) global-to-local interference = (% accuracy local consistent − % accuracy local inconsistent)/(% accuracy local consistent), and (b) local-to-global interference = (% accuracy global consistent − % accuracy global inconsistent)/(% accuracy global consistent).

We implemented this strategy to identify developmental differences that are often masked by large intra-subject variability. For example, participants who respond slowly to consistent stimuli in the Navon task may also respond slowly to inconsistent stimuli because of slow motor responses and not because they are susceptible to interference. It is difficult, if not impossible, to make this distinction when analyzing mean reaction times for consistent and inconsistent stimuli alone. Instead, the contributions of motor and interference effects are more easily dissociated when baseline performance is considered.

Results

The relationship between IQ (full-scale, performance and verbal according to Wechsler scales) and measures of RT and accuracy was first examined to ensure that intelligence did not significantly contribute to the variability in performance. No significant correlations were found in either the TD or ASD group, all $p > .05$, and the effects of Wechsler IQ were not considered influential in the interpretation of the findings (see Supplementary Tables 1a and b for further information).

Additional Pearson bivariate correlations were conducted between RT and accuracy to establish whether fast responses were correlated with poor accuracy. These revealed that RT correlated negatively with accuracy scores for consistent stimuli in the local condition for both the TD, $r(40) = -.328$, $p = .039$, and ASD, $r(39) = -.348$, $p = .030$, groups. It is important to note, however, that these correlations were negative and in the opposite direction of what was expected for a speed-accuracy trade-off. The absence of any significant, positive correlation indicated that there was no speed-accuracy trade-off in either participant group, all $p > .05$ (see Supplementary Table 2 for further information).

Developmental Trajectories for Global and Local Reaction Time and Accuracy

We found a significant relationship between age and overall global and local RT in both the TD [global RT: $R^2 = .70$, $F(1,39) = 89.87$, $p < .0001$; local RT: $R^2 = .70$, $F(1,39) = 88.44$, $p < .0001$] and ASD groups [global RT: $R^2 = .22$, $F(1,38) = 10.24$, $p = .003$; local RT: $R^2 = .26$, $F(1,38) = 13.00$, $p = .001$] (Fig. 2). However, this was not the case for accuracy and we found no significant relationship between age and global or local accuracy in the TD group [global accuracy: $R^2 = .011$, $F(1,39) = .41$, $p = .527$; local accuracy: $R^2 = .004$, $F(1,39) = .14$, $p = .711$]. We found a single, significant relationship between age and global accuracy in the ASD group, but not between age and local accuracy [global accuracy: $R^2 = .19$, $F(1,38) = 8.75$, $p = .005$; local accuracy: $R^2 = .10$, $F(1,38) = 3.89$, $p = .056$]. Given the lack of a clear correlation between age and performance accuracy, this data was not included in the subsequent trajectory analysis. Instead, differences in accuracy both within and between groups were analyzed with non-parametric tests. These analyses are provided in the supplementary material.

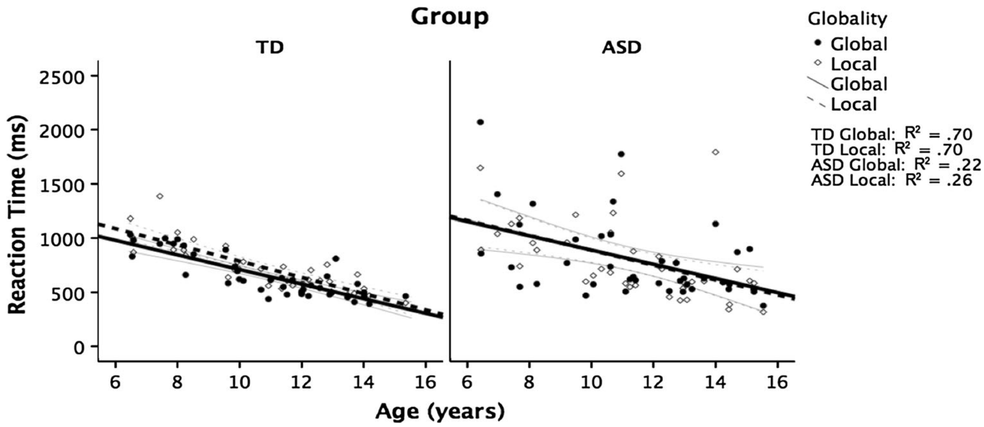

Fig. 2 Developmental trajectories of mean reaction time [milliseconds (ms)] for global and local conditions in typically developing (TD, *left panel*) and autism spectrum disorder (ASD, *right panel*) groups. *Markers* show individual reaction time values averaged across consistent and inconsistent stimuli in each condition (closed—global condition; open—local condition). *Bold lines* represent the regression lines, or trajectories, for the global (*solid*) and local (*dotted*) conditions, respectively. *Thin lines* show ∓95 % confidence intervals. R^2 reflects the proportion of variance explained by each trajectory

Comparisons of Global and Local Reaction Time *Within* Groups

We first examined performances in global and local conditions by comparing trajectories *within* TD and ASD groups (Fig. 2). Comparisons of RT measures revealed that the TD group responded faster to global than to local stimuli, $F(1,39) = 19.76$, $p < .0001$, $\eta_p^2 = .37$ (main effect of globality)[1] and their RTs improved significantly with age, $F(1, 38) = 110.18$, $p < .0001$, $\eta_p^2 = .74$ (main effect of age). No significant interaction between globality and age was present, indicating that RT developed similarly in both global and local conditions, $F(1,38) = 1.29$, $p = .262$, $\eta_p^2 = .12$, global RT: B = −67.49 ms/year and local RT: B = −75.07 ms/year (linear slopes). In the ASD group, overall RT for global and local stimuli was similar, $F(1,38) = .04$, $p = .846$, $\eta_p^2 = .01$ (see footnote 1, main effect of globality) and decreased with age, $F(1,37) = 13.08$, $p = .001$, $\eta_p^2 = .26$ (main effect of age). Further, RT in the global and local conditions improved with age at a similar rate, $F(1,37) = .05$, $p = .823$, $\eta_p^2 = .01$ (globality × age interaction), global RT: B = −65.60 ms/year and local RT: B = −68.68 ms/year. These results suggest that generally, global and local RT follow similar developmental trajectories *within* the TD and ASD groups.

[1] The degrees of freedom for the main effect of globality are different from other terms of the analyses because this main effect was taken from a separate ANOVA analysis that excluded age as a covariate. For additional information, see (Thomas et al. 2009) and (Annaz et al. 2010).

Comparisons of Global and Local Reaction Time *Between* Groups

A mixed ANCOVA, with group and globality as factors and age as a covariate, indicated that there was a similar relationship between RT and age across global and local conditions for both groups, $F(1,75) = .084$, $p = .773$, $\eta_p^2 = .01$ (group × globality × age); $F(1,75) = 0.042$, $p = .839$, $\eta_p{}^2 = .01$ (group × age); $F(1,75) = 0.471$, $p = .494$, $\eta_p{}^2 = .01$ (globality × age) (see Fig. 3a, b). Both groups performed similarly across global and local conditions at 6 years, $F(1,75) = 1.24$, $p = .269$, $\eta_p^2 = .02$ (group × globality). Moreover, RT did not differ significantly by group, $F(1,75) = 1.15$, $p = .287$, $\eta_p^2 = .02$ (main effect of group) or by globality, $F(1,75) = 1.77$, $p = .187$, $\eta_p^2 = .02$ (main effect of globality) at 6 years. Age, however, was a significant predictor of RT, $F(1,75) = 46.72$, $p < .0001$, $\eta_p^2 = .38$ (main effect of age). These analyses confirm that, similar to the trajectories *within* groups, the trajectories for global and local RT were similar *between* groups.

Analysis of Interference

Standard multiple regression models were used to examine the influence of interference on global and local RT across groups. Two sets of two models were constructed. The first set of models evaluated developmental and group differences in consistent global and local RT, whereas the remaining two models examined global-to-local and local-to-global interference.

The dependent variable in the first set of models was RT for consistent stimuli in each condition. Group, age and the

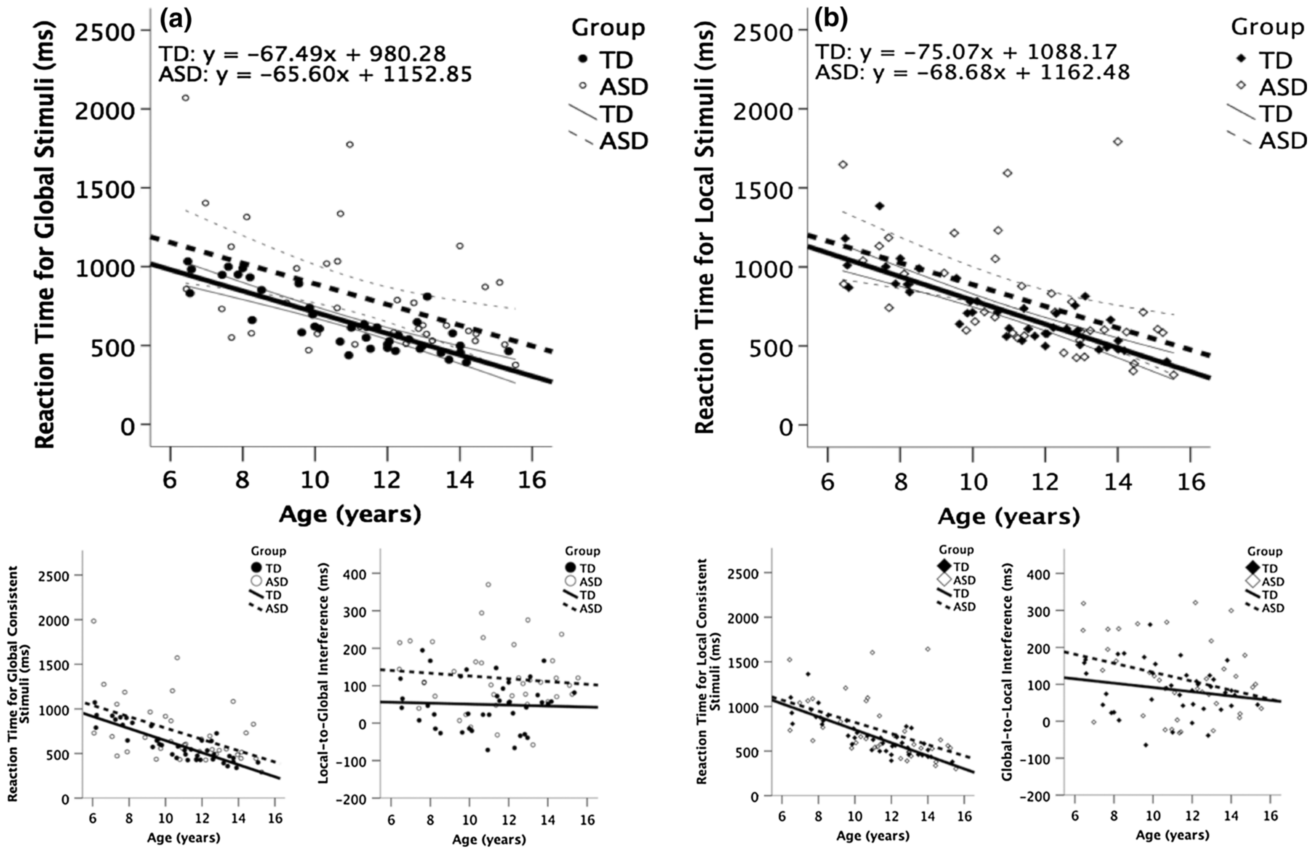

Fig. 3 A comparison of developmental trajectories for the typically developing (TD) and autism spectrum disorder (ASD) groups in the global (**a**, *left*) and local (**b**, *right*) conditions. The *large graphs in the upper left and right* depict reaction times (RTs) averaged across stimuli (i.e., consistent and inconsistent). The *small graphs situated below and to the left of the large graphs* depict RTs for consistent stimuli only. The *small graphs situated below and to the right of the large graphs* depict differences in RTs for consistent and inconsistent stimuli (i.e., interference = inconsistent RT − consistent RT). *Markers* represent the individual RT values in each condition [closed—TD; open—ASD groups (upper)]. *Bold* and *dotted lines* show the respective developmental trajectories of the TD and ASD groups. *Thin lines* show ∓95 % confidence interval. RTs are reported in milliseconds (ms)

interaction between group and age were entered as predictors. In the second set of models, the dependent variable was a calculated score of interference, as described previously in the "Methods" section. Group, age, RT for consistent stimuli (either global or local), along with the interaction of group and age, were used as predictors. Assumptions of normality, linearity, homoscedasticity and multicollinearity were satisfied. The categorical predictor of group was dummy-coded. The TD group was coded as 0 and the ASD group as 1. The continuous predictors of age and RT for consistent stimuli were centered as deviation scores from their overall respective mean to ease the interpretation of the parameters in the regression models, as described in Hayes (2013).

Tables 4 and 5 encompass both full and simplified models of global-to-local and local-to-global interference, respectively. The full models include all predictors and interactions, whereas the simplified models include only predictors and interactions that were significant or central to the main research question. This approach reduces the complexity of the models and consequently, facilitates the understanding of interference effects. The results below therefore report only on the simplified models.

Differences in Global and Local Consistent Reaction Time: Baseline Measures

The model of 'baseline' global performance was significant, $F(3,78) = 14.88$, $p < .0001$ (Table 2). Both group and age significantly predicted global consistent RT; the ASD group was significantly slower than the TD group, $t(75) = 2.81$, $p = .006$, and RT for global consistent stimuli decreased with age, $t(75) = -4.33$, $p < .0001$. However, this decrease in RT was similar between groups, because the interaction between group and age was not significant, $t(75) = .09$, $p = .930$. Therefore, the baseline

Table 2 Standard multiple regression examining the effect of group and age on reaction time (RT, ms) for consistent stimuli in the global condition

Predictor	B	SE (B)	p
Intercept	629.16**	36.00	<.0001
Group	145.08*	51.71	.006
Age	−65.58**	15.14	<.0001
Group × age	1.82	20.67	.930

Dependent variable: Global consistent RT

TD = 0; ASD = 1

$R^2 = .37$; * $p < .05$; ** $p < .001$

performance of the ASD group was slower than that of the TD group in the global condition, but performance in both groups improved similarly with age.

The model of 'baseline' local performance was also significant, $F(3,78) = 14.80$, $p < .0001$ (Table 3). Age was significant in the model, $t(75) = -4.81$, $p < .0001$, but group, $t(75) = 1.77$, $p = .081$, and the interaction of group and age were not, $t(75) = .50$, $p = .616$. Thus, RT for local consistent stimuli decreased with age, but baseline local performance was similar between groups.

Differences in the Effect of Global-to-Local and Local-to-Global Interference on Reaction Time Between Groups and Across Ages

The model of global-to-local interference approached significance, $F(3,78) = 2.68$, $p = .053$, but group, age, and RT for consistent stimuli in the local condition were not significant predictors, all $p > .05$ (Table 4).

However, the overall model of local-to-global interference was significant, $F(3,78) = 9.82$, $p < .0001$ (Table 5), and both group, $t(75) = 3.06$, $p = .003$, and consistent RT for global stimuli, $t(75) = 3.29$, $p = .002$, were significant predictors. This result revealed a greater local-to-global interference effect in the ASD than the TD group after controlling for RT for consistent stimuli in the global condition. Age was not a significant predictor, $t(75) = 1.32$, $p = .192$, which indicated no significant developmental change in this effect.

Table 3 Standard multiple regression examining the effect of group and age on reaction time (RT, ms) for consistent stimuli in the local condition

Predictor	B	SE (B)	p
Intercept	677.30**	36.15	<.0001
Group	91.88	51.92	.081
Age	−73.07**	15.20	<.0001
Group × age	10.47	20.76	.616

Dependent variable: Local consistent RT

TD = 0; ASD = 1

$R^2 = .37$; * $p < .05$; ** $p < .001$

Discussion

Summary of Findings

Previous studies have shown that individuals with ASD have an enhanced ability to process detailed or local stimuli (Behrmann et al. 2006b). This observation is consistent with two of the most prominent neuro-cognitive theories in ASD: weak central coherence (Happé and Frith 2006) and enhanced perceptual functioning (Mottron and Burack 2001; Mottron et al. 2006). There are few studies, however, that have examined when such processing emerges during development and how the presence of conflicting global and local information influences performance across ages.

Here, we provide the first, cross-sectional developmental trajectory of global and local processing in the Navon task, and identify a significant effect of local-to-global interference in individuals with ASD. Importantly, these findings indicate that global and local RT develops at a similar rate in children and adolescents with ASD. Moreover, trajectories of their global and local performances, as reflected by measures of RT, are similar to those of TD children when the effects of interference are not explicitly considered.

The pattern of results is strikingly different when the effects of interference are parsed. Individuals with ASD respond slower than TD individuals to consistent stimuli in the global condition, suggesting a slower 'baseline' performance. Analyses of interference further reveal a significantly greater local-to-global interference in individuals with ASD relative to their TD comparisons, even when accounting for the slower baseline performance. In contrast, though individuals with ASD and their TD comparisons experience some global-to-local interference, this does not differ significantly between groups. These findings demonstrate that children and adolescents with ASD, relative to TD comparisons, may be generally slower to respond to global information in the absence of interference. In the presence of interference, however, they experience a stronger influence of local on global information processing.

Table 4 Standard multiple regression examining the effect of group, age and consistent reaction time on global-to-local interference (RT, ms)

Predictor	Full model			Simplified model		
	B	SE (B)	p	B	SE (B)	p
Intercept	83.46*	24.74	.001	87.94**	14.29	<.0001
Group	49.74	29.32	.094	33.03	19.99	.102
Age	−10.17	11.06	.361	−8.40	4.90	.091
Local consistent RT	−.061	.125	.624	.012	.04	.783
Group × age	−.907	12.65	.943	–	–	–
Group × local consistent RT	.074	.134	.582	–	–	–
Age × local consistent RT	.006	.031	.846	–	–	–
Group × age × local consistent RT	.019	.035	.583	–	–	–

Dependent variable: Difference in local RT = local inconsistent RT − local consistent RT

TD = 0; ASD = 1

R^2 = .11 (simplified model); * $p < .05$; ** $p < .001$

Table 5 Standard multiple regression examining the effect of group, age, and consistent reaction time on local-to-global interference (RT, ms)

Predictor	Full model			Simplified model		
	B	SE (B)	p	B	SE (B)	p
Intercept	37.43	19.24	.056	56.43**	12.00	<.0001
Group	76.81*	23.53	.002	54.38*	17.77	.003
Age	3.88	9.96	.698	5.50	4.18	.192
Global consistent RT	.072	.132	.588	.125*	.038	.002
Group × age	.188	11.30	.987	–	–	–
Group × global consistent RT	.068	.139	.629	–	–	–
Age × global consistent RT	−.043	.031	.178	–	–	–
Group × age × global consistent RT	.052	.034	.133	–	–	–

Dependent variable: Difference in global RT = global inconsistent RT − global consistent RT

TD = 0; ASD = 1

R^2 = .28 (simplified model); * $p < .05$; ** $p < .001$

Trajectories of Global and Local Processing

The developmental trajectories investigated in this study offer a novel perspective of age-related changes in global and local processing. Trajectories for RT in both the global and local conditions were surprisingly quite similar in both the ASD and TD groups. Closer inspection, however, revealed an interesting pattern. Contrary to predictions of faster local performances, global and local trajectories were similar *within* the ASD group. Trajectories within the TD group were somewhat different. The TD group responded faster to stimuli in the global than local condition, partially converging with findings of a global advantage in children and adolescents (Poirel et al. 2008; Porporino et al. 2004; but see Scherf et al. 2008, 2009; Mondloch et al. 2003), in some cases as early as 6 years (Poirel et al. 2011).

The comparison between groups revealed expected age-related improvements in RT. Unexpectedly, however, the trajectories of the TD and ASD groups were similar in the global and local conditions. These results indicate that generally, global and local trajectories are similar between ASD and TD groups from childhood to adolescence. The similarity in performances suggests that 6-year old children with ASD are quite capable of processing global and local information when instructed to do so (Bernardino et al. 2012; Koldewyn et al. 2013). This finding is consistent with current proposals that visuo-spatial perception in ASD is not simply characterized by local superiorities or global deficits (d'Souza et al. 2015; Happé and Booth 2008; Happé and Frith 2006; Mottron and Burack 2001).

Interfering Local Information Slows Global Performance in ASD

The specific consideration of baseline performance extends previous findings of interference effects. This approach is advantageous in that it isolates interference effects that could otherwise be attributed to slower performances in general. The results from these analyses revealed important differences in baseline performance between groups, particularly within the global condition. Participants with ASD responded slower than TD participants to consistent stimuli in the global condition but not in the local condition. Thus, individuals with ASD were significantly slower than TD individuals in global 'baseline' performance, converging with other findings of a reduced global advantage in ASD (see Muth et al. 2014 for meta-analysis).

When taking into account this difference, the comparison of computed interference scores revealed that the effect of local-to-global interference was significantly higher in the ASD than the TD group. This meant that participants with ASD were significantly slower than TD participants when asked to identify the global letter in the presence of inconsistent information at the local level. There was no significant effect of age, however, suggesting that any changes in local-to-global interference during development could not be deduced from our regression model.

The strong influence of local-to-global interference in ASD is consistent with some (Behrmann et al. 2006a; Rinehart et al. 2000; Wang et al. 2007; see Van der Hallen et al. 2014 for meta-analysis), but not all previous findings (Koldewyn et al. 2013; Scherf et al. 2008). Scherf and colleagues (2008), for example, did not find a clear local precedence in children or adolescents with ASD relative to their TD peers, but instead reported this in adults with ASD. They also found that while TD individuals become more sensitive to global information with age, individuals with ASD do not. Specifically, they suggested that individuals with ASD do not develop a global advantage in the same way that TD individuals do across development. The trajectories in our study, however, demonstrate improvements in both global and local performances. This possibly suggests that sensitivity to both types of information increases with age. It is in keeping with the findings of this study, though, that local information may remain more dominant than global information in ASD.

The discrepancy in findings between our study and that of Scherf et al. (2008) may be due to differences in participant groups, and particularly relate to their inclusion of adult participants. Inspection of their figure displaying calculated global advantage scores reveals a strong influence of these participants on their pattern of findings. It is therefore unclear how strongly, or even if, this effect would have presented without the inclusion of such participants. This comparison of developmental findings is difficult, however, because of the differences in analytic approaches across studies. Scherf et al. (2008) used age bins and a simple linear regression to examine global advantages, whereas the presented study used cross-sectional trajectories and standard multiple regressions to examine interference.

Despite these differences, what appears to be consistent across these studies is that local information plays an important role in the visual processing of individuals with ASD. Importantly, the local-to-global interference effect reported here is consistent with findings from a comprehensive meta-analysis of global and local processing in ASD (Van der Hallen et al. 2014). Moreover, it aligns well with the proposal of the EPF model that global information processing is less mandatory and more optional in ASD.

Interference: A Question of Top-Down or Bottom-up Processes

One possible explanation for the stronger local-to-global interference in ASD may relate to differences in higher-order, cognitive functions (i.e., top-down processes), specifically inhibition (Christ et al. 2011; Geurts et al. 2014a, b). Indeed, an inability to inhibit one level of processing prevents the successful processing of another. It follows then that if individuals with ASD cannot successfully inhibit local information, this would impact upon their processing of global information. It is therefore intuitive that difficulties in these top-down processes may account for the effect of local-to-global interference in terms of RT and accuracy. While this idea is in line with reports of executive functioning deficits in ASD (e.g., Ozonoff et al. 1991; Verte et al. 2006), the selectivity of the interference reported here makes it difficult to understand how higher-order processes are responsible for this effect. If inhibitory problems were solely responsible, we would have expected an equal global-to-local interference effect in ASD. It is thus unlikely that higher-order processes can fully explain these findings.

Another possible explanation is that the local-to-global interference effect in ASD may be more related to perceptual than to cognitive processes (i.e., bottom-up processes). That is, the reported interference may not necessarily reflect a decreased ability to inhibit distractor information. Rather, costs incurred between inconsistent and consistent RTs may simply relate to local and global information processing at a perceptual level. For example, differences in the ability to process spatial frequencies may account for the increased local-to global interference effect in ASD.

Two important factors support this idea. First, there is evidence for atypical spatial frequency processing in ASD (Guy et al. 2015; Jemel et al. 2010; Kéïta et al. 2014; Vlamings et al. 2010). Some reports suggest that individuals with ASD, relative to TD individuals, show an increased sensitivity and processing bias for high spatial frequency information (Kéïta et al. 2014). Second, there are established links between the processing of spatial frequency information and performances in the Navon task

(Badcock et al. 1990; Lagasse 1993). Specifically, studies in TD individuals demonstrate that low spatial frequency information signals the global content of the Navon task, whereas high spatial frequency information signals the local content. Taken together, this evidence suggests that atypical perceptual processes may underlie the local-to-global interference seen in ASD.

One potential caveat to this account is that participants with ASD responded as quickly as TD participants to consistent stimuli in the local condition. Presumably, if individuals with ASD process high spatial frequency information better than TD individuals, they would have responded faster in this condition. This, however, was not the case. This account is thus promising but also preliminary, and warrants a cautions interpretation. Future studies in ASD will need to directly examine the effects of spatial frequency information on performances in the Navon task, using approaches similar to those reported in the face perception literature (e.g., Deruelle et al. 2004; Leonard et al. 2013).

Global and Local Order

One intriguing possibility is that the finding of local-to-global interference in ASD may be explained in the context of the availability of global and local information, as discussed in Van der Hallen et al. (2014). Global information is readily available to TD individuals and becomes increasingly important over time. By adulthood, the gist is perceived rather effortlessly and automatically, but the parsing of individual elements occurs later (Kimchi 1992). This temporal distinction of global and local perception is consistent with the Reverse Hierarchy Theory (Hochstein and Ahissar 2002; Ahissar and Hochstein 2004), which suggests that perception follows a rapid global to local progression in TD individuals. Specifically, preliminary perception (i.e., "vision at a glance" or "explicit perception") relies on object and category representations in high-level areas (i.e., inferotemporal cortex), whereas late perception (i.e., "vision with scrutiny" or "implicit perception") relies on parsing of details in low-level areas (i.e., primary visual cortex). This theory thus suggests that perception firstly depends on access to the gist and secondly on access to details in TD individuals.

In contrast, the findings from the present study suggest that the opposite may be true in ASD. Global processing appears to take more time in individuals with ASD than TD individuals, especially in the presence of interfering local information. This slowing suggests that while global processing is unimpaired, it may not form the basis of preliminary perception in ASD. Access to detailed information may supersede global information in early perception, suggesting a difference in the timing of global and local perception. It is therefore possible that perception progresses from local to global information processing in ASD (Van der Hallen et al. 2014).

With this in mind, future research would benefit from an investigation of how experience shapes the temporal aspects of global and local processes in ASD. Atypical visual behaviours early in life, such as lateral glances (Mottron et al. 2007), reduced visual exploration (Leekam et al. 2007) and preoccupation with parts of objects (American Psychiatric Association 2013) may influence perception and possibly, lead to a visual expertise for detailed information with age. Therefore, it may be the case that this early exposure causes a more automatic processing of local than global information in ASD.

Conclusions

The findings presented here provide, for the first time, cross-sectional developmental trajectories of global and local visual processing in children and adolescents with ASD. They reveal important differences in terms of local interference on global information processing in well-defined sample of children and adolescents with ASD. The developmental findings shed some light on inconsistencies within the existing literature by demonstrating that local interference may be more important in ASD than local information processing on its own.

Recent work calls for a closer examination of adolescents with ASD and suggests that this developmental stage may be a more important period of perceptual and cognitive change than previously thought (Picci and Scherf 2014). This proposal, together with the results from the present study, highlights the need for longitudinal studies to better elucidate how the effects of interference manifest and evolve with time. This will be particularly important to understand whether a similar or stronger local-to-global interference effect is present in adults with ASD. A clearer understanding of this interference effect in ASD may ultimately help to identify the optimal age at which specific interventions and learning strategies may be most effective.

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