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Global and local visual processing in autism – a co-twin-control study

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Background: Autism Spectrum Disorder (ASD) is associated with altered global and local visual processing. However, the nature of these alterations remains controversial, with contradictory findings and notions ranging from a reduced drive to integrate information into a coherent 'gestalt' ("*weak central coherence*" = *WCC*) to an *enhanced perceptual functioning (EPF)* in local processing. **Methods:** This study assessed the association between autism and global/local visual processing, using a large sample of monozygotic (MZ) and dizygotic (DZ) twins ($N = 290$, 48% females, age = 8–31 years). The Fragmented Pictures Test (FPT) assessed global processing, whereas local processing was estimated with the Embedded Figures Test (EFT) and the Block Design Test (BDT). Autism was assessed both categorically (clinical diagnosis), and dimensionally (autistic traits). Associations between visual tasks and autism were estimated both across the cohort and within-twin pairs where all factors shared between twins are implicitly controlled. **Results:** Clinical diagnosis and autistic traits predicted a need for more visual information for gestalt processing in the FPT across the cohort. For clinical diagnosis, this association remained within-pairs and at trend-level even within MZ twin pairs alone. ASD and higher autistic traits predicted *lower* EFT and BDT performance across the cohort, but these associations were lost within-pairs. **Conclusions:** In line with the WCC account, our findings indicate an association between autism and reduced global visual processing in children, adolescents and young adults (but no evidence for EPF). Observing a similar association within MZ twins suggests a non-shared environmental contribution. **Keywords:** Autism Spectrum Disorder; global/local visual processing; central coherence; detail focus; co-twin-control design.

Introduction

In order to make sense of the visual surrounding, elements of visual information are typically automatically grouped to meaningful wholes (global processing) in human perception. The flow of visual information from primary to higher order visual areas (bottom-up) is, already at the earliest levels, modulated by projections coming from higher order visual regions (top-down; Dakin & Frith, 2005). Global processing depends on both, the low-level grouping of features such as contour fragments that is achieved by an interplay between bottom-up and top-down processing, and the matching of the image which is created by the grouped elements with memory representations, strongly depending on top-down processing (Van Eylen, Boets, Steyaert, Wagemans, & Noens, 2015). The shift from a more piecemeal-oriented processing of single elements in isolation of their context (local processing) to a globally oriented visual processing as the unaware cognitive default occurs around four to six years of age while adult-like levels of global visual perception are reached around the age of nine (Kimchi, Hadad, Behrmann, & Palmer, 2005; Poirel, Mellet, Houdé, & Pineau, 2008).

In individuals diagnosed with Autism Spectrum Disorder (ASD) the balance between global and local visual processing seems to be different from the general population (Happé & Booth, 2008; Simmons et al., 2009). Two historically prominent accounts, also representing different poles of approaches to the phenomenon, are the (original) *Weak Central Coherence* (WCC) account (Frith, 1989) and the notion of *Enhanced Perceptual Functioning* (EPF; Mottron & Burack, 2001; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). The original WCC account suggested that individuals with ASD have a reduced drive to focus on the global gestalt of visual information as compared to typically developed (TD) individuals, resulting in both, difficulties to integrate information to a global whole and superior performance on tasks requiring local focus. However, explicit task instructions to focus on global aspects can diminish such group differences (Koldewyn, Jiang, Weigelt, & Kanwisher, 2013; Plaisted, Swettenham, & Rees, 1999; Wang, Mottron, Peng,

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Berthiaume, & Dawson, 2007). The revised notion of WCC therefore suggested that people with ASD carry a cognitive default to prefer local over global information that leads to superior local processing and typically slower but not impaired global processing (Happé & Frith, 2006). The EPF model proposes enhanced low-level perception in ASD due to an over-development or an incomplete shift towards more globally oriented perception (Mottron & Burack, 2001; Mottron et al., 2006). According to EPF, global processing is unaltered in ASD but less mandatory compared to TD. Recent accounts to explain the potential mechanisms of a more locally biased processing in ASD suggested further a reduced influence of prior knowledge on perception (Pellicano & Burr, 2012) or an altered updating of these representations (Van de Cruys et al., 2014).

The nature and extent of altered global and local visual processing in ASD remains unclear due to the inconsistency of the findings, which might be accounted for by the variability of study designs, small sample sizes, different age ranges, and heterogeneity of ASD phenotypes (Simmons & Todorova, 2018). Crucially, global and local processing are directly competing in most global/local tasks, making it hard to distinguish effects of reduced global from superior local processing (Booth & Happé, 2016). A task that has been suggested to tap more specifically on global processing (Booth & Happé, 2016) is the Fragmented Pictures Test (FPT; Kessler, Schaaf, & Mielke, 1993; Snodgrass & Corwin, 1988). In the FPT, the amount of visual information (fragments) of fragmented drawings of objects is stepwise increased until a whole picture is visible. The testee is supposed to identify each object with as little visual information as possible. Autistic individuals commonly need more visual information in order to identify the objects in the FPT and similar tests (Booth & Happé, 2016; Evers et al., 2014; Happé & Booth, 2008; Van Eylen et al., 2015). This global processing disadvantage in ASD on the FPT might depend on difficulties with the top-down matching rather than the bottom-up global grouping drive (Van Eylen et al., 2015).

Local visual processing in ASD is often assessed with visual search figure-disembedding tasks such as the Embedded Figures Test (EFT), requiring the participant to detect simpler shapes embedded in larger complex pictures (Witkin, Oltman, Raskin, & Karp, 1971). Further, superior performance of individuals with ASD in the Block Design Test (BDT) has been interpreted as resulting from superior local processing, since the test requires participants to segment a geometric figure into sub-components (Bölte, Hubl, Dierks, Holtmann, & Poustka, 2008; Shah & Frith, 1993). Autistic individuals outperform TD controls on the BDT, especially for stimuli where the outline of the color pattern does not coincide with the edges of the blocks, requiring a higher degree of active segmentation (Caron, Mottron, Berthiaume, & Dawson, 2006). Recent meta-analyses involving EFT and BDT indicated either superior performance of individuals with ASD compared to TD (Muth, Hönekopp, & Falter, 2014) or no such advantage (Van der Hallen, Evers, Brewaeys, Van den Noortgate, & Wagemans, 2015). Potential explanations for these conflicting findings could be the heterogeneity in study designs and the impact of IQ as moderator variable. For instance, studies where the ASD group was slightly higher in IQ than the control group showed the strongest local advantage while no such superiority was seen in studies where the ASD group had a slightly lower IQ (Muth et al., 2014).

Since ASD is likely to form the extreme end of a continuum of autistic traits (Constantino et al., 2003), investigating the relationship between visual processing and quantitative autistic traits might be more informative than a solely categorical approach. Local processing advantages in the EFT (Cribb, Olaithe, Di Lorenzo, Dunlop, & Maybery, 2016) and the BDT (Best, Moffat, Power, Owens, & Johnstone, 2008; Stewart, Watson, Allcock, & Yaqoob, 2009) have been observed to be associated with higher autistic traits in the general population. High autistic traits also correlate with reduced global motion processing in both neurotypical and clinically enriched samples (Grinter et al., 2009; Van Boxtel & Lu, 2013; Van Eylen et al., 2015). In the fragmented object outline task, which is similar to the FPT but differentiates different degrees of object homogeneity, the need for more visual information to identify objects that are more homogeneous was higher in children and adolescents with ASD but did not correlate with autistic traits (Van Eylen et al., 2015). Together these results suggest that certain aspects of global/local visual processing might covary with autistic traits along the broader autism spectrum while other aspects might be solely associated with clinically relevant trait levels. In order to be able to address this point, our study investigated global/local visual processing in association with both categorical ASD (clinical diagnosis) and continuously distributed autistic traits.

Little is known regarding the genetic and environmental contributions to global/local visual processing in ASD. Twin designs provide an important approach to disentangle genetic from environmental effects within this association (Mevel, Fransson, & Bölte, 2015). A recent twin study assessed autistic adolescents, their non-autistic co-twins and unrelated TD controls with a large battery of tests including global/local processing tasks, supporting the notion of reduced global processing in ASD beyond familial confounding (Brunsdon et al., 2015). More specifically, twins with ASD performed on average poorer than the control twin group in two out of three tasks tapping global processing, namely in the Sentence Completion Task (requiring to complete a sentence taking its global meaning into account) and in the Planning Drawing Task (requiring a global plan for copying line figures). However, since they conducted group mean comparisons irrespective of zygosity status, they could not directly assess the association within-pairs nor specifically investigate non-shared environmental contributions.

This study is the first to investigate altered global and local visual processing in ASD utilizing a *co-twin-control design* (see Appendix S1) in a large clinically enriched sample of monozygotic (MZ) and dizygotic (DZ) twins. Using this approach, associations were tested within-twin pairs where they are adjusted for familial (genetic and shared environmental) factors which includes controlling for 100% genetics within-MZ pairs (McGue, Osler, & Christensen, 2010). In line with the hypotheses of a reduced global processing in ASD, we predicted that twins with ASD diagnosis and higher autistic traits would require more visual information in the FPT (more fragments) for the correct identification of the fragmented objects. In line with the EPF model, we predicted that both ASD diagnosis and higher autistic traits would predict faster disembedding within the EFT and better performance in the BDT. Since FPT performance has been demonstrated to be influenced by experience (Russo, Nichelli, Gibertoni, & Cornia, 1995), we predicted to find an association between ASD diagnosis/autistic traits and FPT performance within-MZ twins, indicating a non-shared environmental contribution. For the local tasks, we did not make specific predictions regarding the influence of non-shared environment.

Methods

Participants

Twins (352 individuals) from the Roots of Autism and ADHD Twin Study in Sweden (RATSS; Bölte et al., 2014) were mainly recruited (~10% response rate) from the Child and Adolescent Twin Study in Sweden (CATSS; Anckarsäter et al., 2011). Both MZ and DZ twin pairs from CATSS were prioritized if differing by at least two points on the ASD or the ADHD subscale of the *Autism-Tics, ADHD and other Comorbidities inventory* (A-TAC), a parent telephone interview assessing ASD and comorbidities (Larson et al., 2010). We also selected pairs where both twins scored above or below the cut-offs for ASD or ADHD on the A-TAC. The actual diagnostic status and concordance/discordance were however determined after assessing the twins during their visit in our lab, irrespective of the A-TAC. Additionally, we aimed for similar numbers of MZ and DZ pairs as well as males and females. Zygosity was determined on a panel of 48 single nucleotide polymorphisms for 128 pairs (Hannelius et al., 2007), or a 4-item zygosity questionnaire (14 pairs). Since we aimed to include as many twin pairs as possible, we included three pairs where zygosity was not determined (pending zygosity pairs) in all analyses except for the final analysis step where only MZ pairs were selected. Eight DZ pairs were excluded because they were of opposite sex, which might have affected the outcome while eight pairs are not sufficient to model within-pair sex-effects. Further, eight individuals from families with two twin pairs or triplets were excluded. Finally, 19 pairs with incomplete data (38 individuals) were excluded because at least one of the twins had missing data in any of the three visual tests, autistic traits or IQ. The included sample consisted of 145 twin pairs (87 MZ, 55 DZ, three pairs with pending zygosity). Of these 290 individuals, 64 had an ASD diagnosis and the amount of pairs that were discordant for ASD diagnosis (i.e. only one twin of the pair fulfilling criteria for an ASD diagnosis) was similar between MZ (16 pairs) and DZ twins (19 pairs). Within the same sample, 135 pairs (91% of MZ and 88% of DZ pairs) differed in autistic traits (i.e. by at least one point on the Social Responsiveness Scale 2nd edition = SRS-2). For a summary of sample characteristics, see Table 1.

Ethical considerations

Informed consent was obtained from all participants or their caregivers and ethical approval for the study was given by the Regional Ethical Review Board in Stockholm.

General procedure

Twins were assessed by a team of experienced clinicians and consensus ASD diagnosis was supported by patient's medical history, in addition to a set of standardized diagnostic tools that included the Autism Diagnostic Interview – Revised (ADI-R; Rutter, Le Couteur, & Lord, 2003) and the Autism Diagnostic Observation Schedule (ADOS or ADOS-2; Lord et al., 2012). Autistic traits were estimated via parental ratings on the SRS-2, adult- and child-versions (Constantino & Gruber, 2005; Frazier et al., 2014). Total raw scores were used as recommended for research settings (Constantino & Gruber, 2005).

IQ was assessed using the Wechsler Intelligence Scales for Children or Adults fourth edition (WISC-IV/WAIS-IV; Wechsler, 2003, 2008). Since the BDT, which is a sub-test of the WISC and WAIS, was an outcome measure in this study, it was not included in the calculation of the IQ score, but replaced by the Picture Completion Task.

Local – global tasks

Global processing was estimated with the Fragmented Pictures Test (FPT; Kessler et al., 1993), which assesses the ability to integrate visual fragments into a meaningful whole. Participants were presented with 10 sets of fragmented drawings of objects that were gradually completed in 10 sequential steps. The participants were instructed to browse through the images keeping a steady pace, and to respond verbally when they identified the depicted object. Incorrect responses were noted, but participants were allowed to continue and give several responses. The FPT score was calculated as the sum of images needed across trials in order to identify the objects correctly. All participants completed the same FPT version and hence raw scores were used for the analyses.

Local processing was assessed with the child or adult versions of the Embedded Figures Test (EFT) and the Block Design Test (BDT). On the EFT, participants identified simple forms hidden within complex figures and the mean time across trials until correctly circumscribing the hidden figure was calculated as EFT speed. If participants were unable to find the embedded figure in the allotted time, the maximum time was noted. Child and adult version differ in the amount of trials (20 to 25 in the child version vs 12 in the adult version) and the maximum time per trial (120sec in the child version vs 180sec in the adult version). Further, the hidden figures always have the form of either a "house" or a "tent" in the child version while these are geometric shapes (e.g. a triangle) in the adult version. Children up to 13 years completed the child version while older participants completed the adult version (Karp & Konstadt, 1963; Witkin et al., 1971). Ten twin pairs where at least one of the twins was unable to complete the adult version, mostly because of low intellectual ability, completed the child version despite being older than 13 years.

Table 1 Sample characteristics

	Whole sample	MZ	DZ	Pending zygosity	Male	Female
Total *N* individuals	290	174	110	6	152	138
N individuals with ASD	64	36	27	1	38	26
N individuals belonging to ASD Concordant pairs	28	20	8	0	16	12
N individuals belonging to ASD Discordant pairs	72	32	38	2	44	28
Age range	8–31	9–29	8–31	8–24	8–31	8–29
Mean Age (*SD*)	16.9 (5.8)	17.3 (5.7)	16.0 (5.7)	18.7 (8.3)	15.7 (5.2)	18.1 (6.1)
Mean SRS (*SD*)	40.9 (32.9)	35.5 (30.8)	49.9 (34.6)	30.7 (27.3)	43.4 (32.6)	38.2 (33.1)
Mean Δ SRS (*SD*)	24.0 (25.7)	18.1 (22.2)	33.4 (28.2)	25.3 (28.9)	24.1 (25.8)	23.9 (25.8)
Mean IQ (*SD*)	98.8 (15.4)	98.8 (16.0)	99.0 (14.5)	103.7 (15.2)	98.3 (15.5)	99.7 (15.4)
Mean Δ IQ (*SD*)	10.9 (9.4)	8.4 (8.8)	14.6 (9.0)	14.0 (15.7)	11.2 (10.2)	10.5 (8.5)

ASD, Autism Spectrum Disorder; *SD*, Standard Deviation; SRS, Social Responsiveness Scale-2 total raw scores; Mean ΔSRS, is the average difference between twins of a pair in SRS-2 total raw scores; MZ, monozygotic twin pairs; DZ, dizygotic twin pairs; Pending zygosity, pairs that were not identified as either MZ or DZ yet; IQ, Wechsler Intelligence Scale General Ability Index score for children or adults; Mean ΔIQ, average difference between twins of a pair in IQ.

On the BDT, participants arranged sets of two-colored blocks within a respective time limit (30–120s.) in order to create up to 14 target patterns presented in order of ascending difficulty. In order to achieve a higher score, a fast and accurate reproduction of all patterns was required. There are slight differences in the administration and scoring of the child and adult version, e.g. target patterns and time limits for each trial. The raw scores where converted to scaled scores, ranging from one to 19. Children up to sixteen years completed the child version while older participants completed the adult version.

Due to the differences between child and adult versions of the EFT and the BDT, the scores were first z-transformed separately for the adult (EFT: 88 twin pairs; BDT: 83 twin pairs) and child versions (EFT: 57 twin pairs; BDT: 62 twin pairs), before analyzing them together.

Statistical analyses

Global processing, as reflected by the FPT performance, and local processing, as reflected by EFT and BDT performance, were tested for their relationships with both ASD diagnosis and autistic traits within the same sample. Linear regressions were conducted in R using the Generalized Estimating Equations framework with doubly robust standard errors (drgee), which performs regression analyses without any distributional assumptions (Zetterqvist & Sjölander, 2015). ASD diagnosis or autistic traits served as predictor variables and FPT score, z-transformed EFT speed, or z-transformed BDT score as outcome variables within the same sample. The estimated regression coefficients in these analyses represent how many units in the outcome one unit change in exposure variable predicts, e.g. one unit change in the autistic trait severity scale (or ASD diagnosis yes or no) predicts 'b' (the regression coefficient) units change in visual task performance. Since three outcome measures were tested for their association with ASD diagnosis/autistic traits, a Bonferroni corrected alpha-level ($\alpha = .05$) was set to $p = .017$ in order to adjust for multiple comparisons. *p*-values (2-sided) *below .05* but exceeding the applied alpha-level threshold were explicitly described as *trends*.

A) In a first step, linear regressions were conducted across individuals, first unadjusted (crude) and then adjusted for IQ, sex and age. **B)** Consecutively, *conditional* linear regressions were conducted using a unity link function while twin-pair specific intercepts were assumed in order to assess the same relationships within-twin pairs – crude and adjusted for IQ. More precisely, the difference within a pair on the exposure variable, e.g. autistic trait severity, was correlated with the difference in the outcome variable, i.e. visual task performance, within that same pair. **C)** Within-pair associations showing at least a trend ($p < .05$) were further assessed within-MZ twins alone in order to investigate whether they were influenced by non-shared environmental factors.

Results

Global processing

Across individuals, we found that ASD diagnosis predicted a need for more visual information in the FPT to close gestalt, both in the crude model and when adjusting for the covariates (see Table 2). Crude and adjusted associations were of similar magnitude within-pairs, albeit with higher *p*-values, with the crude model surviving correction but the adjusted model reducing to a trend (two-sided). The association was at trend level for the crude and adjusted model within-MZ twins.

Similar to the results for ASD diagnosis, higher autistic traits predicted higher FPT scores. This association was significant in the crude model across individuals and a trend in the crude within-pair model, but no longer a trend in adjusted models and within-MZ twins alone, while the regression coefficient remained similar.

The results reported above are two-sided although they are in line with our hypotheses. When considering one-sided *p*-values, the associations between ASD diagnosis and FPT in the adjusted within-pair model, the crude within-MZ model and the crude within-pair association between autistic traits and FPT survive Bonferroni correction.

Local processing

Across individuals, ASD diagnosis predicted slower disembedding speed in the EFT (higher EFT speed score), and this association remained when adjusting for the covariates (see Table 3). ASD diagnosis was not associated with BDT performance (see Table 4). There was no association between ASD diagnosis and EFT or BDT performance within-pairs, in neither crude nor adjusted models.

Higher autistic traits predicted slower EFT performance across individuals, even when adjusting for the covariates. Higher autistic traits also predicted worse BDT performance in the crude model, but this association vanished after adjusting for covariates. Within-pairs, autistic traits were neither associated with disembedding speed in the EFT nor BDT performance.

Discussion

This study investigated the relationship between autism and global/local visual processing using a co-twin-control design. Our findings confirm reduced global processing to be associated with both ASD diagnosis and autistic traits. The association with ASD diagnosis remained as a trend within-MZ twin pairs, suggesting non-shared environmental contribution. We did not find evidence for superior local processing in ASD but in contrast *slower* performance in local processing within the EFT across individuals but not within-pairs, suggesting a strong influence of familial factors.

Global processing

Our results indicate reduced global processing, as reflected by the need for more visual information in the FPT, in association with ASD diagnosis and higher autistic traits. This finding is in line with previous studies (Booth & Happé, 2016; Evers et al., 2014; Happé & Booth, 2008; Scheurich et al., 2010; Van Eylen et al., 2015). In contrast, studies using tasks requiring the identification of *non-figural shapes* show typically intact contour integration in ASD (Annaz et al., 2010; Del Viva, Igliozzi, Tancredi, & Brizzolara, 2006). One explanation is that the identification of non-figural shapes depend more on "low-level" bottom-up contour integration abilities (Simmons et al., 2009) while the identification of fragmented *objects* relies largely on top-down matching between the visual inputs with memory representations, which might be more affected in ASD (Van Eylen et al., 2015).

In our study, being diagnosed with ASD or having a two *SD* higher level of autistic traits across the sample (66 more points on the SRS-2) predicted the need for about four more images on the FPT. These associations pointed into the same direction within-pairs, even though reducing to a trend for autistic traits. The association with ASD diagnosis remained significant after adjusting for the covariates (age, sex and IQ) and even after additionally controlling for the total amount of errors, thereby considering that autistic individuals may have responded more cautiously (see Appendix S1, Follow-up-1). This association also remained a trend in the crude model within-MZ twins, suggesting a non-shared environmental influence. Non-shared environmental factors in ASD can for instance be intrauterine growth restrictions (Class, Rickert, Larsson, Lichtenstein, & D'Onofrio, 2014; Losh, Esserman, Anckarsäter, Sullivan, & Lichtenstein, 2012). Genetic and shared environmental impact is however reflected by the stronger associations (i.e. slightly higher regression estimates) across individuals compared to within-pairs. The higher *p*-values in the within-pair

Table 2 Results from crude and adjusted linear regressions with either ASD diagnosis or autistic traits as main predictors of global visual processing assessed with the FPT

	ASD/Autistic traits			IQ			Sex			Age		
Predictor/Model	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
ASD diagnosis												
Across crude	**3.60**	**.99**	**3e^{-4}**									
Across adjusted	**2.61**	**.84**	**2e^{-3}**	***.05***	***.02***	***.03***	.59	.77	.45	**.47**	**.07**	**2e^{-11}**
Within crude	**2.89**	**1.14**	**.01**									
Within adjusted	***2.29***	***1.05***	***.03***	**−.12**	**.05**	**.01**						
Within MZ crude	***3.13***	***1.40***	***.03***									
Within MZ adjusted	***2.49***	***1.23***	***.04***	−.09	.07	.16						
Autistic traits												
Across crude	**.06**	**.01**	**2e^{-5}**									
Across adjusted	.03	.01	.06	−.05	.03	.05	−.68	.77	.38	**−.45**	**.07**	**1e^{-9}**
Within crude	***.04***	***.02***	***.03***									
Within adjusted	.03	.02	.11	**−.11**	**.05**	**.01**						
Within MZ crude	.04	.02	.08									
Within MZ adjusted	.03	.02	.21	−.09	.07	.18						

Results from crude & adjusted models of ASD and autistic traits predicting global processing as measured by the FPT (visual information needed). Significant outcomes (threshold = $p < 0.017$ at Bonferroni corrected α-level of .05) are printed in BOLD, values indicating a trend (uncorrected $p < .05$, 2-sided) are marked in BOLD and italics. ASD, Autism Spectrum Disorder, *b*, non-standardized regression estimate; *SE*, standard error; FPT, Fragmented Pictures Test.

Table 3 Results from crude and adjusted linear regressions with either ASD diagnosis or autistic traits as main predictors of local processing assessed with the EFT

	ASD/Autistic traits			IQ			Sex			Age		
Predictor/Model	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
ASD diagnosis												
Across crude	**.50**	**.14**	**$4e^{-4}$**									
Across adjusted	**.35**	**.12**	**.01**	**−.03**	**$4e^{-3}$**	**$2e^{-16}$**	.07	.12	.53	.01	.01	.19
Within crude	.26	.21	.22									
Within adjusted	.50	6.73	.94	**−1.32**	**.25**	**$1e^{-7}$**						
Autistic traits												
Across crude	**.01**	**$2e^{-3}$**	**$2e^{-6}$**									
Across adjusted	**.01**	**$2e^{-3}$**	**$2e^{-3}$**	**−.03**	**$4e^{-3}$**	**$3e^{-15}$**	.06	.12	.59	***.02***	***.01***	***.04***
Within crude	.01	$4e^{-3}$	.06									
Within adjusted	.09	.14	.50	**−1.26**	**.25**	**$5e^{-7}$**						

Results from crude & adjusted models of ASD and autistic traits predicting global processing as measured by the FPT (visual information needed). Zygosity-group specific models were not calculated since the whole sample within-pair estimates were not close to a trend. Significant outcomes (threshold = $p < 0.017$ at Bonferroni corrected α-level of .05) are printed in BOLD, values indicating a trend (uncorrected $p < .05$, 2-sided) are marked in BOLD and italics. ASD, Autism Spectrum Disorder, *b*, non-standardized regression estimate; *SE*, standard error; EFT, Embedded Figures Test.

Table 4 Results from crude and adjusted linear regressions with either ASD diagnosis or autistic traits as main predictors of local processing assessed with the BDT

	ASD/Autistic traits			IQ			Sex			Age		
Predictor/Model	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*	*b*	*SE*	*p*
ASD diagnosis												
Across crude	−.25	.17	.15									
Across adjusted	−.05	.12	.65	**.03**	**$3e^{-3}$**	**$<2e^{-16}$**	.12	.11	.29	**−.03**	**.01**	**$4e^{-3}$**
Within crude	−.12	.20	.54									
Within adjusted	.03	.18	.89	**.03**	**.01**	**$1e^{-7}$**						
Autistic traits												
Across crude	**−.01**	**$2e^{-3}$**	**.01**									
Across adjusted	$-1e^{-3}$	$2e^{-3}$	.66	**.04**	**$3e^{-3}$**	**$<2e^{-16}$**	.12	.11	.29	**−.03**	**.01**	**.01**
Within crude	$-3e^{-3}$	$3e^{-3}$	.19									
Within adjusted	$3e^{-4}$	$2e^{-3}$	.91	**.03**	**$6e^{-3}$**	**$3e^{-7}$**						

Results from crude & adjusted models of ASD and autistic traits predicting global processing as measured by the FPT (visual information needed). Zygosity-group specific models were not calculated since the whole sample within-pair estimates were not close to a trend. Significant outcomes (threshold = $p < 0.017$ at Bonferroni corrected α-level of .05) are printed in BOLD. ASD, Autism Spectrum Disorder, *b*, non-standardized regression estimate; *SE*, standard error; BDT, Block Design Test.

analyses and especially within-MZ twin pairs alone might potentially be due to the reduced power. Our results are complementing previous findings of reduced global processing in twins with ASD compared to their co-twins (Brunsdon et al., 2015). In contrast to this previous study, we used a co-twin-control design and a different global processing measure, assessed the association with both categorically and dimensionally defined autism and in addition within-MZ twins alone. Also consistent with previous findings (Scheurich et al., 2010; Van Eylen et al., 2015) older individuals performed faster in the FPT in our study (see Table 2), which corroborates the hypothesis that FPT performance depends on top-down matching abilities which mature with age.

Local processing

In line with the conclusion of a recent meta-analysis (Van der Hallen et al., 2015), we did not find superior local processing in the EFT or the BDT to be associated with ASD across individuals or within-twin pairs. However, these findings contradict the EPF account and the outcome of another meta-analysis detecting superior performance in EFT and BDT – even though the heterogeneity between study outcomes was substantial and modulated by IQ (Muth et al., 2014). Since *slower* EFT speed in association with ASD diagnosis/higher autistic traits across individuals was even observed when controlling for IQ in our study and when excluding lower functioning individuals (IQ < 70; see Appendix S1, Follow-up-2), we conclude that IQ was not primarily driving this association. We further found very similar results when re-running the analyses with the percentage of correct responses given within the allotted time in the EFT as outcome (see Appendix S1, Follow-up-3), which is likely less impacted by participants general processing speed and a more cautious response style. Importantly, we did not find an association between autism and local processing within-pairs, in line with the results by Brunsdon et al. who found that adolescent twins with ASD did not perform differently from to their unaffected co-twins on the EFT and BDT (Brunsdon et al., 2015). We believe that familial factors probably influenced the associations between ASD and slower EFT performance in studies that did not take those factors into account.

General discussion

The inclusion of lower functioning individuals and the almost even distribution of sex in our study makes our outcomes more generalizable in respect to the entire autism spectrum. On the other hand, this might make the study less sensitive for detecting effects that are specific to certain autism sub-groups that have been more commonly assessed in previous studies, such as males with ASD in the normative IQ range.

The associations between autistic traits and visual tests were weaker in a sub-sample of 95 twin pairs where none of the twins had an ASD diagnosis but remained in unadjusted models across individual (see Appendix S1, Follow-up-4), indicating that they were partly but not entirely driven by individuals with ASD diagnosis. Further, a strengthening of the adjusted association between autistic traits and FPT performance (then reaching trend level) when additionally controlling for ADHD diagnosis suggests that this additional adjustment might account for some otherwise unexplained variance, even though ADHD diagnosis itself was not associated with visual test performance (see Appendix S1, Follow-up-5). When exploring relationships between the performance in the three visual tests used in this study (see Appendix S1, Follow-up-6) we found significant correlations across individuals, indicating that better performance in one test was related to better performance in the other tests. This is in line with previous observations (Happé & Booth, 2008) and speaks for an influence of general performance speed rather than a trade-off between global and local processing.

Longitudinal studies should assess whether altered visual task performance might emerge or vanish over age in individuals with ASD. Three-year olds diagnosed with ASD did for instance not perform differently from age-matched controls in a version of the FPT adapted for young children (Jobs, Falck-Ytter, & Bölte, 2018).

Limitations

This study does not allow inference regarding directionality since it is correlational. Further, while our findings underline the importance of non-shared environmental factors to global processing ability in ASD, we cannot conclude anything regarding the nature of these environmental factors. We acknowledge that the limited number of discordant pairs might have reduced the power for the within-MZ analyses.

Moreover, most global/local processing tasks including EFT and BDT are blended tasks, operationalizing both global and local processing simultaneously (Booth & Happé, 2016). This might have contributed to the heterogeneity of EFT and BDT results in the literature and the discrepancy between our and a multitude of previous findings. Importantly, no visual task assesses global or local processing in isolation from other abilities, and alterations in executive functions commonly found in ASD (Lai et al., 2017) might affect performance in these tasks. Further, the tasks used here were not designed to investigate the impact of low-level stimuli features which have previously been shown to modulate performance in relation with ASD and autistic traits (Bertone, Mottron, Jelenic, & Faubert, 2005; Van der Hallen, Chamberlain, de-Wit, & Wagemans, 2018) and do not allow conclusions whether observed differences are related to lower or higher level visual processing (Grinter et al., 2009; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005). Future twin studies should address these gaps by using tasks systematically manipulating features, such as the amount of target lines continuing into the context in the EFT (Van der Hallen et al., 2018).

Conclusions

Our results confirm that individuals with ASD diagnosis or higher autistic traits need more visual fragments to form a meaningful gestalt on the FPT, indicating a reduced global visual processing. For ASD diagnosis, this association remained within-pairs and within MZ twins, suggesting the importance of non-shared environmental factors. Our results do not support an enhanced local visual processing in association with ASD.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Appendix S1.

Co-twin-control design and follow-up analyses.

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Key points

- Individuals with ASD have been suggested to have a reduced global and enhanced local visual processing but the results are largely inconsistent.
- Our results indicate reduced global processing in individuals with a diagnosis of ASD or higher autistic traits, even when controlling for familial confounders using a co-twin-control design.
- The association was similar within monozygotic twins where it remained as a trend for ASD diagnosis, suggesting that non-shared environmental factors play a role in this association.
- The latter might have implications for interventions targeting global processing abilities.
- In contrast, our results do not support an association between local visual processing and ASD or autistic traits.

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