

Face processing among twins with and without autism: social correlates and twin concordance

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Abstract

Autism spectrum disorder (ASD) has a strong heritable basis, as evidenced by twin concordance rates. Within ASD, symptom domains may arise via independent genetic contributions, with varying heritabilities and genetic mechanisms. In this article, we explore social functioning in the form of (i) electrophysiological and behavioral measures of face processing (P1 and N170) and (ii) social behavior among child and adolescent twins with ($N = 52$) and without ASD ($N = 66$). Twins without ASD had better holistic face processing and face memory, faster P1 responses and greater sensitivity to the effects of facial inversion on P1. In contrast, N170 responses to faces were similar across diagnosis, with more negative amplitudes for faces vs non-face images. Across the sample, stronger social skills and fewer social difficulties were associated with faster P1 and N170 responses to upright faces, and better face memory. Twins were highly correlated within pairs across most measures, but correlations were significantly stronger for monozygotic vs dizygotic pairs on N170 latency and social problems. We suggest common developmental influences across twins for face processing and social behavior, but highlight (i) neural speed of face processing and (ii) social difficulties as important avenues in the search for genetic underpinnings in ASD.

Key words: autism; face processing; P1; N170; heritability

Introduction

Autism spectrum disorder (ASD) has a strong heritable and genetic basis. Defined by early and pervasive difficulties in social communication and restricted or repetitive interests and behaviors, ASD is observed in monozygotic (MZ) twin pairs at concordance rates of 60–90%, whereas rates among dizygotic (DZ) twins are estimated at 5–20% (Bailey et al., 1995; Folstein and Rutter, 1977; Rutter, 2005; Hallmayer et al., 2011; Ronald and Hoekstra, 2011). Relative to the general population, non-twin siblings of individuals with ASD carry a heightened risk of an ASD diagnosis (Ozonoff et al., 2011; Gronborg et al., 2013) and of more subtle concerns related to social development and behavior (Rutter, 2005; Warren et al., 2012; Messinger et al., 2013).

Furthermore, on average, parents and siblings of individuals with ASD display elevated levels of a broader phenotype trait characterized by non-clinical levels of difficulties in social reciprocity, communication and behavioral flexibility (Gerds and Bernier, 2011), further supporting a genetic link.

Recent efforts to characterize the genetic bases of ASD have focused on the disorder not as a unitary construct but rather as a set of skill domains that may be 'fractionable' (Mazefsky et al., 2008; Dworzynski et al., 2009; Robinson et al., 2012). This framework suggests that the core symptom domains within ASD—social impairments, communication deficits and restricted or repetitive behaviors and interests—may develop via separate and distinct genetic mechanisms. Such an approach identifies skill areas of highest heritability, and presumably strongest genetic

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influence, to facilitate the identification of genetic mechanisms within ASD. To date, analyses of genetic correlations reveal sizeable but unique genetic contributions to social, communication and behavioral symptoms among twins with ASD (Mazefsky et al., 2008; Dworzynski et al., 2009), suggesting largely independent genetic pathways. Similar effects have been observed with regard to ASD-like traits within general population samples as well (Ronald et al., 2006; Robinson et al., 2012).

Within the social domain, face processing has particular promise for this approach. Compared with typically developing individuals, those with ASD show altered face processing across a variety of tasks. Face detection and recognition are impaired when tasks carry memory demands, often despite intact or enhanced abilities with non-face stimuli such as animals or buildings (Tantam et al., 1989; Boucher and Lewis, 1992; Weigelt et al., 2012). Individuals with and without ASD also appear to differ in their default strategies for processing faces, such that ASD is associated with a relatively stronger focus on featural rather than configural or holistic information (Wallace et al., 2008), as well as differences in visual attention to the eye and mouth regions of faces (Klin et al., 2002). Higher order tasks such as affect recognition are also impaired in ASD, over and above any effect of general intellectual functioning (Lozier et al., 2014).

Electrophysiological studies provide converging evidence of ASD-related alterations to face processing mechanisms. Two event-related potential (ERP) components most relevant to faces are the P1 and N170, both of which are well established with neurotypical adults. The P1 is a positive-going deflection peaking ~100 ms post-stimulus onset, thought to index early visual attention. The N170 is a negative-going component peaking ~170 ms after the onset of a stimulus, observed over posterior temporal regions. Often considered to be face-sensitive, the N170 is larger and faster peaking to faces than to other images, and is larger but slower following inverted relative to upright faces (Bentin et al., 1996; Rossion et al., 1999; Itier and Taylor, 2002). Among individuals with ASD, researchers have documented slowed P1 and N170 responses to faces (McPartland et al., 2004; O'Connor et al., 2005), reduced N170 amplitude (O'Connor et al., 2005) and reduced sensitivity to upright vs inverted faces in the P1 and N170 responses relative to controls (McPartland et al., 2004; Hileman et al., 2011; Webb et al., 2012). However, such differences have not been documented universally, and may vary with participant age, symptom profile and task (Jemel et al., 2006).

Within the general population, face processing abilities stem from both heritable and environmental influences. Twin correspondence is higher for MZ than DZ twin pairs in facial recognition and face inversion (Zhu et al., 2010), and heritability estimates for ERP responses to changes in facial expressions fall at 36–64% (Anokhin et al., 2010). Nevertheless, both behavioral and biological indices of face processing may be modified through experience. Reduced visual input during early development, such as that associated with bilateral congenital cataracts in infancy, disrupts face recognition throughout development (Geldart et al., 2002), with corresponding alterations to P1 and N170 amplitudes (Mondloch et al., 2013). At the other extreme, behavioral training to teach face processing strategies to adults with ASD results in more accurate behavioral performance as well as reduced P1 amplitude to faces (Faja et al., 2012).

With this context in mind, the goals of the current study were threefold. First, we sought to further characterize the electrophysiological response to human faces among children and adolescents with and without ASD. Although alterations to P1 and N170 responses have been documented with regard to

adults and young children (McPartland et al., 2004; Webb et al., 2006, 2012), our knowledge of these mechanisms in children with ASD is limited (Hileman et al., 2011). On the basis of previous literature, we anticipated that individuals with ASD would evidence slower P1 and N170 responses to upright faces, and would show a blunted inversion effect for these components relative to non-ASD peers.

Second, we sought to explore links between face processing (both neural response and behavioral performance) and social behavior. We anticipated that both faster neural responses to faces and more accurate face processing (in the form of higher scores on tasks of holistic processing and memory) would be associated with stronger parent-reported social skills across multiple measures.

Finally, we sought to examine heritable aspects of face processing and social behavior. Although established data suggest heritability of behavioral indices of face processing, the current literature offers very little insight into the heritability of P1 and N170 components, and no studies to date have examined such heritability among individuals with ASD. On the basis of existing literature, we anticipated that twins would be correlated on measures of face processing and social functioning (suggesting shared developmental influences), but also predicted that MZ twins would be more highly correlated than DZ twins (suggesting heritable influences).

Materials and Methods

Participants

Families of twins were recruited from community schools, groups for parents of multiple births and a University autism center registry. Twin pairs between the ages of 5 and 30 years with and without ASD were invited to participate based on parent report that both twins were typically developing, both twins had ASD, or one twin had ASD. Exclusion criteria included significant sensory or motor impairment, neurological disease such as Fragile X, major psychiatric disorder (e.g. schizophrenia), history of head injury or seizures and current use of medications known to affect EEG. Twin pair zygosity was recorded on the basis of parent report and verified through medical records when available. This strategy resulted in 118 individuals—56 sets of twins (27 MZ, 29 DZ) and 2 sets of triplets (1 MZ, 1 DZ). Both male ($n = 74$) and female ($n = 44$) participants were included. See Table 1 for participant sex and diagnosis by zygosity.

Individuals with a known or suspected diagnosis of ASD completed the Autism Diagnostic Observation Schedule (Lord et al., 2003) and their parent completed the Autism Diagnostic Interview, Revised (Lord et al., 1994). Among the 56 twin pairs, both twins received ASD diagnoses in 19 pairs (ASD-concordant pairs); only one twin received an ASD diagnosis in 12 pairs (ASD-discordant pairs) and neither twin received an ASD diagnosis in 25 pairs (non-ASD pairs). In one of the triplet families, none of the individuals had ASD; in the second, two of the three siblings had ASD. Twins with ASD had a mean age of 10.9 years ($s.d. = 4.5$, range = 5–22) and twins without ASD had a mean age of 9.6 years ($s.d. = 3.4$, range = 5–21), a nonsignificant difference ($P > 0.05$). Supplementary Table S1 provides sample breakdown by sex, diagnosis and zygosity.

Procedures

Participants and their parents completed two visits, each consisting of a behavioral and electrophysiological battery. Visit A

Table 1. Demographic and diagnostic characteristics of twins/triplets by ASD diagnosis

	Non-ASD	ASD	F	η_p^2
Age (years)	10.1 (3.4)	11.3 (4.4)	3.1	0.03
Verbal IQ	118.8 (12.4)	94.1 (21.9)	59.5***	0.34
Performance IQ	110.5 (11.9)	100.5 (17.8)	13.3***	0.10
Full Scale IQ	116.5 (11.2)	97.4 (19.8)	43.6***	0.27
Holistic face task (% correct)	61.3 (12.1)	60.3 (11.7)	0.16	0.00
Face memory (d')	0.99 (0.33)	0.68 (0.54)	14.9**	0.12
Vineland-2 Social. Std. Score	103.3 (13.9)	73.1 (15.4)	124.9***	0.52
CBCL Social Problems T-score	53.0 (6.2)	65.5 (9.1)	67.5***	0.41
SRS total T-score	44.8 (8.3)	76.4 (12.0)	245.8***	0.71

Notes. For the majority of participants, IQ was assessed with the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). For those younger than 6 years, the Differential Abilities Scale, 2nd Edition (Elliott, 2007) was used instead. Vineland-2, Vineland Adaptive Behavior Scales, 2nd Edition (Sparrow et al., 2005); SRS, Social Responsiveness Scale (Constantino and Gruber, 2005). ** $P < 0.01$. *** $P < 0.001$.

included EEG and behavioral measures of face and social processing. Visit B included EEG and behavioral measures of language and executive functioning. One twin was assigned to Visit A first and the other twin was assigned to Visit B first. Data presented are from Visit A.

Measures and tasks

Face processing, neural responses. EEG was recorded during a target detection task using an EGI 128-channel geodesic net with impedances below 50 k Ω . Participants sat ~75 cm from a computer screen in a sound-attenuated room. When needed, assistants provided behavioral support to maximize attention and minimize extraneous movement. EEG was continuously recorded from the scalp at a sampling rate of 500 Hz, referenced to vertex and bandpass filtered from 0.01 to 100 Hz. To contrast responses to face vs non-face stimuli, participants viewed upright and inverted images of novel human faces and houses, presented in randomized order (Webb et al., 2012). To maximize attention, images of butterflies were interspersed throughout, and participants were instructed to press a button when the image of a butterfly appeared. Each trial consisted of a fixation crosshair (500 ms) then stimulus image (500 ms), with an inter-trial interval of 995–1295 ms. Participants viewed ~200 stimulus images (50 images each of upright faces, inverted faces, upright houses and inverted houses) plus 32 butterfly images, over the course of four blocks. Participants were offered breaks between blocks as necessary; as a result, total task length was ~12 min. Sessions were video-recorded and reviewed in detail, and trials in which the participant looked away from the screen during the stimulus were discarded.

Following collection, data were lowpass filtered at 100 Hz and segmented into trials of 1000 ms with a 500 ms pre-stimulus baseline. Trials with more than 100 μ V variation within any 80 ms window, more than 10 bad channels or eyeblink artifacts were discarded. Channels for which more than 50% of segments were marked bad were replaced, and data were re-referenced to an average reference of all electrodes minus the eye channels. Trials were then baseline corrected according to the 200 ms preceding stimulus onset. Data were retained when a participant had valid data from at least 80% of channels, as well as at least 25% of face-upright trials and at least 25% of overall trials (face/house, upright/inverted). Mean numbers of trials retained for

each participant were similar across all four conditions: face upright ($M = 30.56$, $s.d. = 8.3$), face inverted ($M = 29.89$, $s.d. = 8.4$), house upright ($M = 28.89$, $s.d. = 8.1$) and house inverted ($M = 29.30$, $s.d. = 8.5$).

The P1 and N170 components were extracted from a total of 16 electrodes spanning left lateral (electrodes 58, 59, 64, 65), left medial (66, 70, 71, 72), right medial (77, 84, 85, 90) and right lateral (91, 92, 96, 97) regions. Because these components show developmental shifts in latency, amplitude and morphology over the age range of our sample (Taylor et al., 2004; Hileman et al., 2011), we first divided participants according to age and then determined P1 temporal windows for each age grouping with visual inspection of individual and group-averaged waveforms to ensure veridical identification of the P1 across all electrodes of interest and all task conditions. As a result, P1 peak amplitude and latency to peak were extracted from the following time windows: 65–160 ms for ages 5–7 years (13 twins), 65–175 ms for ages 8–11 years (45 twins), 65–160 ms for ages 12–16 years (15 twins) and 65–135 ms for ages 17 years and older (7 twins). Of note, the length of the P1 temporal window varied across the age groupings and was longest for the 8–11 age group, likely reflecting increased variability in face processing during this developmental period (Taylor et al., 2004).

Consistent with previous research (Kuefner et al., 2010; Hileman et al., 2011), the N170 was then specified as the first negative deflection following the P1 peak, and temporal windows were specified and confirmed individually for each participant through visual inspection.

Electrodes for which the P1 or N170 peak were not clearly visible or were markedly atypical (e.g. reversed polarity) were excluded. To be included, the P1 and N170 had to be present in 50% of the electrodes in a lead group, verified through visual inspection. In total, 80 (28 ASD, 52 non-ASD) and 65 (25 ASD, 40 non-ASD) participants contributed data to P1 and N170 analyses, respectively. Participants with ASD who retained ERP data had better face memory than those with ASD without usable ERP data ($t(49) = -3.35$, $P = 0.002$), but did not differ significantly on the basis of age, holistic face processing accuracy or social functioning on the Child Behavior Checklist (CBCL), Vineland Adaptive Behavior Scale, 2nd Edition (Vineland-2) or Social Responsiveness Scale (SRS). Table 2 presents mean latencies and amplitudes for components of interest. See Figure 1.

Table 2. Means (s.d.) of P1 and N170 latencies (milliseconds) and peak amplitudes (μ V) to faces and houses by group

	Faces		Houses	
	Upright	Inverted	Upright	Inverted
P1				
No ASD				
Latency	106 (11)	112 (12)	123 (14)	126 (12)
Amplitude	13.14 (5.40)	14.39 (6.18)	14.57 (6.17)	14.10 (5.81)
ASD				
Latency	109 (12)	115 (14)	129 (17)	125 (14)
Amplitude	12.02 (5.91)	13.33 (6.27)	13.81 (6.81)	13.09 (6.66)
N170				
No ASD				
Latency	173 (22)	174 (17)	179 (20)	183 (19)
Amplitude	0.27 (3.73)	0.86 (3.64)	4.96 (4.19)	4.57 (3.85)
ASD				
Latency	166 (30)	170 (28)	170 (31)	175 (30)
Amplitude	-2.26 (4.31)	-1.25 (5.49)	3.66 (5.41)	3.20 (5.73)

Holistic processing task. Participants completed a match-to-sample task designed to assess holistic face processing (Faja et al., 2008). Stimuli consisted of 10 child (Joseph and Tanaka, 2003) and 10 adult (Tottenham et al., 2009) faces, in which all core features had been replaced. Within each of 64 trials, participants viewed a whole target face for 3.5 s, followed by a 1-s delay and then a test phase. During the test phase, the target face was shown either as a whole face or as a part (either the eye or mouth region), and was presented alongside a foil image for up to 8 s. Foil images differed from targets by exactly one feature in each trial, and participants were asked to select which image was an exact match for the whole face shown previously. Test trials varied in orientation (whether the target and foil were presented upright vs inverted), test type (whether whole vs part faces) and feature that differed between them (eyes vs mouth). When partial faces were shown for the test phase, they were presented in a rectangle at the same size and location as in the original (whole) target face. In total, 106 participants (42 ASD, 64 non-ASD) contributed complete data.

Face memory. Participants completed the immediate recall phase of the Face Memory subtest of either the *Children's Memory Scale* (CMS; Cohen, 1997), or the *Wechsler Memory Scale*, 3rd Edition (Wechsler, 1997), depending upon age at assessment. In both, participants viewed upright human faces presented in a series, and were then asked to indicate which of a second series of faces they had just seen. Both the learning and test sets consisted of approximately half child and half adult faces. From these measures, we computed d' statistics to assess participants' ability to discriminate familiar faces from novel faces, with higher scores indicating better face memory. In total, 117 participants (51 ASD, 66 non-ASD) contributed data to the face memory task.

Social functioning. Broad social functioning was assessed via parent report in three ways. First, parents completed the Vineland-2 (Sparrow et al., 2005), a semi-structured parent interview, from which the socialization standard score was extracted as a measure of social skill. Second, parents completed the SRS (Constantino and Gruber, 2005), which yields T -scores for social difficulties overall and within subscales measuring social awareness, cognition, communication, motivation and mannerisms (repetitive behaviors and restricted interests). Third, parents completed the CBCL (Achenbach, 1991), which provides T -scores for a variety of subscales; the social problem T -score was extracted as a measure of social difficulties.

Cognitive processing. Intellectual functioning was assessed with standardized measures on the basis of participant age. Participants age 6 years or older completed the *Wechsler Abbreviated Scale of Intelligence* (Wechsler, 1999) and participants younger than 6 years completed the *Differential Abilities Scale*, 2nd Edition (Elliott, 2007). Both measures yield standard scores for verbal, nonverbal and overall intellectual functioning.

Analytic approach

Analyses are presented in accordance with three broad study aims. First, we sought to characterize P1 and N170 components to faces in our unique sample of twins, with particular attention to diagnostic status. Second, we sought to characterize relations between face processing (ERP and behavioral indices) and social functioning in this population. Third, we sought to explore correspondence within twin pairs on measures of face processing

and social functioning. For this third aim, analyses were restricted to those pairs who were concordant for sex (both male or both female) and for diagnosis (both with ASD or neither with ASD). This subsample consisted of 86 individuals in 43 twin pairs: 25 MZ pairs (12 female pairs, 13 male pairs; 9 ASD-concordant pairs, 16 non-ASD pairs) and 18 DZ pairs (3 female pairs, 15 male pairs; 10 ASD-concordant pairs, 8 non-ASD pairs).

Results: face processing

Electrophysiological responses

Latency and amplitude at the peaks of the P1 and N170 deflections were entered into repeated measures analyses of covariance (ANCOVAs) with Stimulus (faces vs houses), Orientation (upright vs inverted) and Hemisphere (left vs right) as within-subjects factors, participant Age as a covariate and Diagnostic Group (presence vs absence of ASD) as a between-subjects factor.

P1 latency, group effects. A main effect of Diagnostic Group was found on P1 latency, $F(1, 77) = 6.90$, $P = 0.01$, $\eta_p^2 = 0.08$, with faster P1 responses among participants without ASD relative to those with ASD. Group interacted with Orientation, $F(1, 77) = 4.70$, $P = 0.03$, $\eta_p^2 = 0.06$, with evidence of faster P1 responding to upright vs inverted images among non-ASD participants, $P < 0.001$, but no orientation effect in those with ASD, $P = 0.58$. Finally, the Group \times Stimulus \times Orientation term was significant as well, $F(1, 77) = 7.91$, $P = 0.006$, $\eta_p^2 = 0.09$. Although both ASD and non-ASD participants showed effects of orientation for both faces and houses, the direction of those effects differed. Although the non-ASD group had faster P1 responses to both faces and house when upright vs inverted, $P_s < 0.05$, the ASD group had a faster P1 to upright vs inverted faces, $P < 0.001$, but also inverted vs upright houses, $P = 0.02$.

P1 latency, general effects. Main effects were observed for Age, $F(1, 77) = 37.95$, $P < 0.001$, $\eta_p^2 = 0.33$, and Stimulus, $F(1, 77) = 25.91$, $P < 0.001$, $\eta_p^2 = 0.25$. The P1 response was faster among older participants, and was faster to faces vs houses. A Stimulus \times Orientation interaction was significant, $F(1, 77) = 19.90$, $P < 0.001$, $\eta_p^2 = 0.21$, such that the P1 was faster to upright vs inverted faces, $P < 0.001$, but did not differ across orientations for houses, $P = 0.47$. However, this was qualified by an interaction with Age (Stimulus \times Orientation \times Age), $F(1, 77) = 8.00$, $P = 0.006$, $\eta_p^2 = 0.09$, and indicated that the effects of Age were most marked for responses to faces rather than houses.

P1 peak amplitude, group effects. There were no main or interactive effects of diagnostic group on P1 peak amplitude.

P1 peak amplitude, general effects. Main effects on P1 amplitude were observed for Stimulus, $F(1, 77) = 8.45$, $P = 0.005$, $\eta_p^2 = 0.10$, and Age, $F(1, 77) = 45.55$, $P < 0.001$, $\eta_p^2 = 0.37$. P1 amplitude was larger for houses than for faces, and tended to decrease with age. The Stimulus \times Age interaction was also significant, $F(1, 77) = 4.72$, $P = 0.03$, $\eta_p^2 = 0.06$, and indicated that the difference between faces and houses decreased with age. A Stimulus \times Orientation interaction was present as well, $F(1, 77) = 7.77$, $P = 0.007$, $\eta_p^2 = 0.09$, such that P1 was larger for faces vs houses when images were upright, $P < 0.001$, but did not differ across stimuli when inverted, $P = 0.45$.

N170 latency, group effects. There were no main or interactive effects of diagnosis.

N170 latency, general effects. Latency of the N170 response was characterized by a main effect of participant Age, $F(1, 62) = 44.55$, $P < 0.001$, $\eta_p^2 = 0.42$, such that N170 latency decreased with age. There were no significant effects of Stimulus or Orientation on N170 latency in our sample.

N170 peak amplitude, group effects. There were no main or interactive effects of diagnosis.

N170 peak amplitude, general effects. Age had a significant main effect on N170 peak amplitude, $F(1, 62) = 27.42$, $P < 0.001$, $\eta_p^2 = 0.31$, which became more negative with increasing age. The main effect of Stimulus was significant as well, $F(1, 62) = 19.86$, $P < 0.001$, $\eta_p^2 = 0.24$, such that peak amplitude was more negative for faces than for houses. Stimulus also interacted with Orientation, $F(1, 62) = 4.66$, $P = 0.04$, $\eta_p^2 = 0.07$. Peak amplitude was more negative for upright vs inverted faces, $P = 0.01$, but there was no effect of Orientation on houses, $P = 0.18$.

Behavioral

Holistic processing task. Accuracy scores were analyzed with a repeated measures ANCOVA with Orientation (upright vs inverted), Trial Type (whole vs part) and Feature (eyes vs mouth) as within subjects factors, Diagnostic Group as a between subjects factor and participant Age as a covariate. Significant main effects were revealed for Diagnosis, $F(1, 103) = 4.17$, $P = 0.04$, $\eta_p^2 = 0.04$, and Age, $F(1, 103) = 56.75$, $P < 0.001$, $\eta_p^2 = 0.36$. Participants without ASD and those who were older were more accurate. Accuracy was also characterized by a Feature \times Group interaction, $F(1, 103) = 5.70$, $P = 0.02$, $\eta_p^2 = 0.05$, such that participants without ASD were more accurate than those with ASD on eyes trials, $P = 0.007$, but the groups were equally accurate on mouth trials, $P = 0.61$. Group also interacted with Orientation and Trial Type, $F(1, 103) = 4.99$, $P = 0.03$, $\eta_p^2 = 0.05$. For participants without ASD, accuracy was higher for whole vs part faces when presented upright, $P < 0.001$, but there was no effect of Trial Type when faces were inverted, $P = 0.23$. A similar pattern was observed for ASD participants but did not reach significance, $P_s > 0.08$. In addition to the main effect of Age, Age interacted with Feature, $F(1, 103) = 5.63$, $P = 0.02$, $\eta_p^2 = 0.05$, such that greater accuracy for eyes vs mouths emerged with age. An Age \times Orientation \times Trial Type interaction was significant as

well, $F(1, 103) = 5.36$, $P = 0.02$, $\eta_p^2 = 0.05$. Greater accuracy for whole vs part faces when upright emerged with age.

Face memory. Accuracy scores (d') were entered into an ANCOVA with Diagnostic Group as a between subjects factor and participant age as a covariate. Twins with and without ASD differed significantly in their ability to discriminate familiar from novel faces, $F(1, 114) = 16.72$, $P < 0.001$, $\eta_p^2 = 0.13$. Twins without ASD (mean $d' = 0.99$) were more accurate in their memory for faces compared with those with ASD (mean $d' = 0.68$). There was no effect of age on face memory, $F(1, 114) = 2.55$, $P = 0.11$, $\eta_p^2 = 0.02$.

Results: correlations between face processing and social behavior

Associations between measures of face processing and social functioning were assessed with partial correlations that controlled for participant age at time of assessment. Correlations across the entire sample are shown in Table 3, and correlations within each diagnostic group separately are presented in Table 4. Across the entire sample, P1 latency was correlated with social functioning as measured by the Vineland-2, CBCL and SRS. See Figure 2. Faster P1 to upright faces corresponded to better social skills and fewer social difficulties. However, it is important to note that diagnostic groups differed significantly with respect to P1 latency and measures of social functioning (Table 1).

Latency of the N170 response was correlated with social difficulties as well, as measured by the CBCL. See Figure 3. Faster N170 responses to upright faces corresponded to fewer social difficulties. N170 latency also correlated with holistic face processing, with faster processing (i.e. shorter latency) corresponding to greater accuracy in the holistic task. However, as shown in Table 3, latencies of the P1 and N170 components were not independent of one another, $r = 0.53$, $P < 0.001$. Further analysis revealed that the correlation between N170 latency and CBCL Social Problems was not significant when controlling for P1 latency, $r = 0.19$, $P = 0.17$, suggesting that fewer social difficulties may be related to faster activation of the larger P1-N170 complex, rather than to N170 latency alone.

With regard to behavioral measures of face processing, accuracy on the holistic face task correlated positively with memory for faces. Both holistic accuracy and memory for faces were significantly correlated with a number of measures of social functioning. Overall, accuracy and memory for faces was associated with better social skills and fewer social difficulties across multiple measures.

Table 3. Partial correlations between ERPs to upright faces, face processing and social behavior for the entire sample

	P1 amplitude	N170 latency	N170 amplitude	Holistic face task ^a	Face memory ^b	Vineland-2 Socialization	CBCL Social Problems	SRS total
P1 latency	0.44***	0.53***	0.35**	-0.19	-0.09	-0.27*	0.27*	0.29*
P1 amplitude	—	0.52**	0.45***	-0.05	0.15	-0.23*	0.10	0.12
N170 latency	—	—	0.31*	-0.25*	-0.11	-0.23†	0.27*	0.23†
N170 amplitude	—	—	—	0.03	0.17	0.13	-0.04	-0.26†
Holistic face task ^a	—	—	—	—	0.31***	0.13	-0.37***	-0.24*
Face memory ^b	—	—	—	—	—	0.43***	-0.28**	-0.43***
Vineland-2 Socialization	—	—	—	—	—	—	-0.70***	-0.82***
CBCL Social Problems	—	—	—	—	—	—	—	0.79***

Notes. Correlations control for participant age, except where cells are shaded. Vineland-2, *Vineland Adaptive Behavior Scales*, 2nd Edition (Sparrow et al., 2005); CBCL, *Child Behavior Checklist* (Achenbach, 1991); SRS, *Social Responsiveness Scale* (Constantino and Gruber, 2005). ^aTotal accuracy. ^b d' statistic. [†] $P < 0.10$. * $P < 0.05$. ** $P < 0.01$. *** $P < 0.001$.

Table 4. Partial correlations between ERPs to upright faces, face processing and social behavior by diagnostic group

	P1 amplitude	N170 latency	N170 amplitude	Holistic face task ^a	Face memory ^b	Vineland-2 Socialization	CBCL Social Problems	SRS Total
Non-ASD								
P1 latency	0.49***	0.60***	0.23	-0.08	0.00	-0.11	0.18	0.16
P1 amplitude	—	0.35*	0.34*	0.06	0.21	-0.25 [†]	0.10	-0.07
N170 latency	—	—	0.14	-0.29 [†]	-0.16	-0.50***	0.45**	0.39*
N170 amplitude	—	—	—	0.17	0.04	0.04	0.03	-0.31 [†]
Holistic face task ^a	—	—	—	—	0.20	-0.11	-0.33*	-0.19
Face memory ^b	—	—	—	—	—	0.25 [†]	-0.27*	-0.12
Vineland-2 socialization	—	—	—	—	—	—	-0.64***	-0.54***
CBCL social problems	—	—	—	—	—	—	—	0.76***
ASD								
P1 latency	0.43*	0.48*	0.56**	-0.18	-0.06	-0.20	0.03	0.08
P1 amplitude	—	0.69***	0.58**	-0.17	0.17	-0.37 [†]	0.07	0.35
N170 latency	—	—	0.43*	-0.30	0.02	-0.22	0.22	0.32
N170 amplitude	—	—	—	-0.29	0.32	-0.21	0.10	0.22
Holistic face task ^a	—	—	—	—	0.31*	0.04	-0.23	-0.14
Face memory ^b	—	—	—	—	—	0.29*	0.00	-0.32*
Vineland-2 socialization	—	—	—	—	—	—	-0.15	-0.55***
CBCL social problems	—	—	—	—	—	—	—	0.42**

Notes. Correlations control for participant age, except where cells are shaded. Vineland-2, *Vineland Adaptive Behavior Scales*, 2nd Edition (Sparrow et al., 2005); CBCL, Child Behavior Checklist (Achenbach, 1991); SRS, *Social Responsiveness Scale* (Constantino and Gruber, 2005). ^aTotal accuracy. ^bCMS *d'* statistic. [†] $P < 0.10$. * $P < 0.05$. ** $P < 0.01$. *** $P < 0.001$.

Results: twin correspondence

One-way random intraclass correlations (ICCs) were computed to assess twin correspondence on ERP and behavioral measures, and Fisher's *r*-to-*z* transformations were used to compare the strength of ICCs across zygosity. Table 5 presents ICCs for each measure by twin zygosity. MZ twins were highly correlated on latencies and amplitudes for both P1 and N170 components. Correlations were also significant for DZ twin pairs, with the exception of N170 amplitude. In addition, accuracy on both the holistic face and face memory tasks was correlated for both MZ and DZ twins. Correlations were all positive in nature, suggesting that twins pairs tended to have similar face processing scores and ERPs. With regard to zygosity differences, although both MZ and DZ pairs were highly correlated on N170 latency, this relation was significantly stronger in MZ twins relative to DZ pairs, suggesting potential genetic influences (Figure 4).

Twin pairs were also highly correlated for social behavior on several measures, including the Vineland-2 Socialization score and the SRS. For social difficulties as assessed by the CBCL Social Problems T-score, only MZ twin pairs were significantly correlated. Moreover, there was a significant difference in the strength of MZ vs DZ correlations on the CBCL Social Problems T-score. MZ twin pairs were more strongly correlated on this measure of social difficulties than were DZ twin pairs, suggesting potential genetic influence on skills indexed by this measure.

Discussion

Our findings yield several insights into face processing and social behavior in ASD. Consistent with expectations, we observed differences between participants with and without ASD on P1 latency to human faces, suggesting a slower P1 response among individuals with ASD. In addition, upright image orientation was associated with shortened P1 latency among twins without ASD, but not twins with ASD. In contrast to previous studies (McPartland et al., 2004; Webb et al., 2012) and to our hypotheses,

Table 5. Twin correspondence on measures of face processing and social functioning

	ICC for MZ pairs	ICC for DZ pairs	Fisher's <i>r</i> -to- <i>z</i>
P1 latency	0.79**	0.57*	0.87
P1 amplitude	0.64*	0.71**	-0.27
N170 latency	0.99***	0.48*	3.35***
N170 amplitude	0.83**	0.34	1.23
Holistic face task	0.52**	0.73***	-0.96
Face memory	0.37*	0.64**	-1.08
Vineland-2 Socialization	0.91***	0.93***	-0.36
CBCL Social Problems	0.93***	0.26	3.61***
SRS total	0.81***	0.85***	-0.38

Notes. Vineland-2, *Vineland Adaptive Behavior Scales*, 2nd Edition (Sparrow et al., 2005); SRS, *Social Responsiveness Scale* (Constantino and Gruber, 2005). * $P < 0.05$. ** $P < 0.01$. *** $P < 0.001$.

however, we did not find effects of ASD diagnosis on the N170 response to faces. Although earlier work suggested reduced N170 speed and amplitude in ASD, we found that the sample as a whole evidenced more negative N170 to faces and upright images, with no effect of ASD diagnosis. The absence of group differences in N170 may reflect the developmental stage of our sample. Hileman et al. (2011) observed a similar pattern of findings—that is, ASD-related alterations to P1 but not N170—and consequently suggested that whereas the N170 response may be the more informative index of face processing for adults, the P1 response may be the more sensitive measure in children. Indeed, we observed a number of main and interactive effects of age on both P1 and N170 in our sample, which had a mean age of ~10 years. In addition, because our sample consists of twin pairs, some individuals in the non-ASD group were twins of individuals with ASD. Given their shared genetic background, these twins were likely more similar in physiology to the ASD group than unrelated individuals would be. To the extent that previous studies compared individuals with ASD to

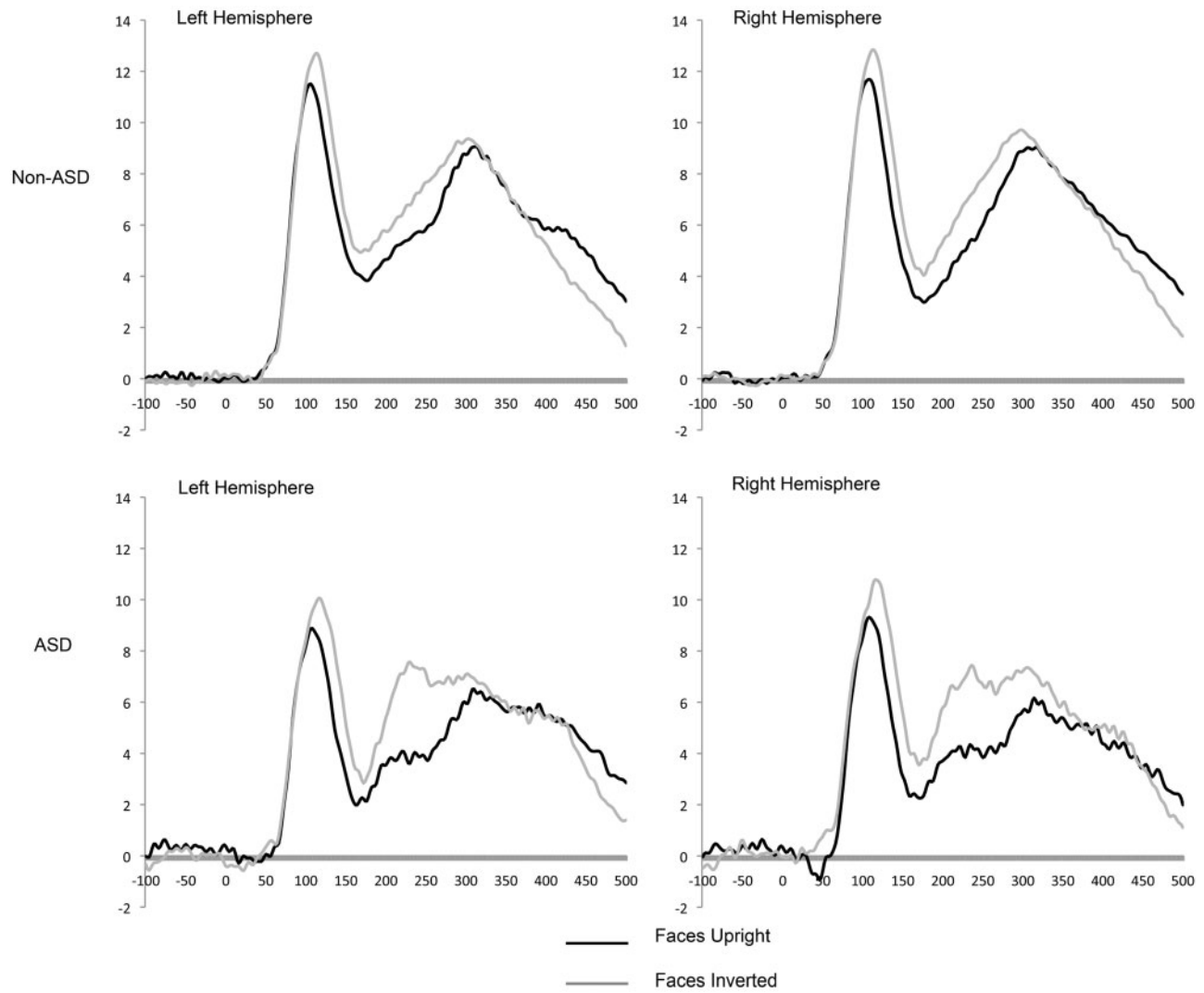


Fig. 1. ERP responses to upright faces and inverted faces by hemisphere for groups with and without ASD.

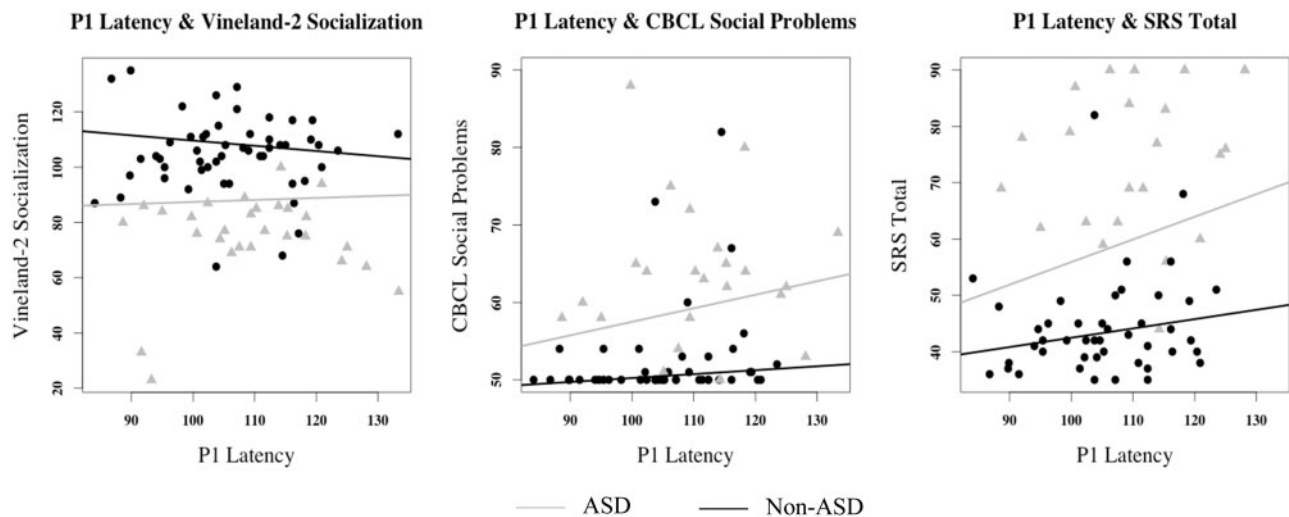


Fig. 2. Correlations between P1 latency and social functioning.

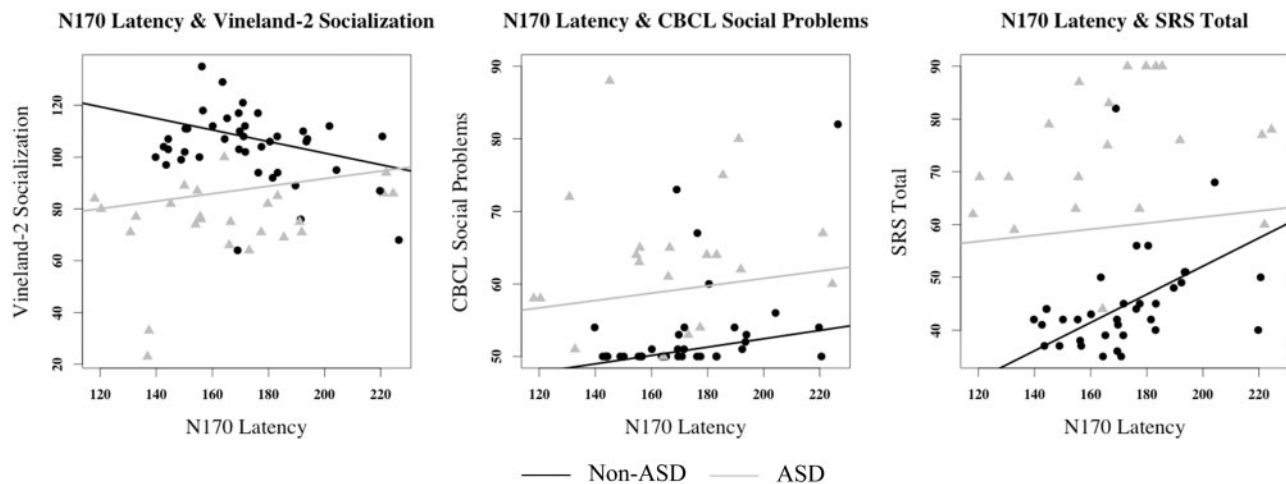


Fig. 3. Correlations between N170 latency and social functioning.

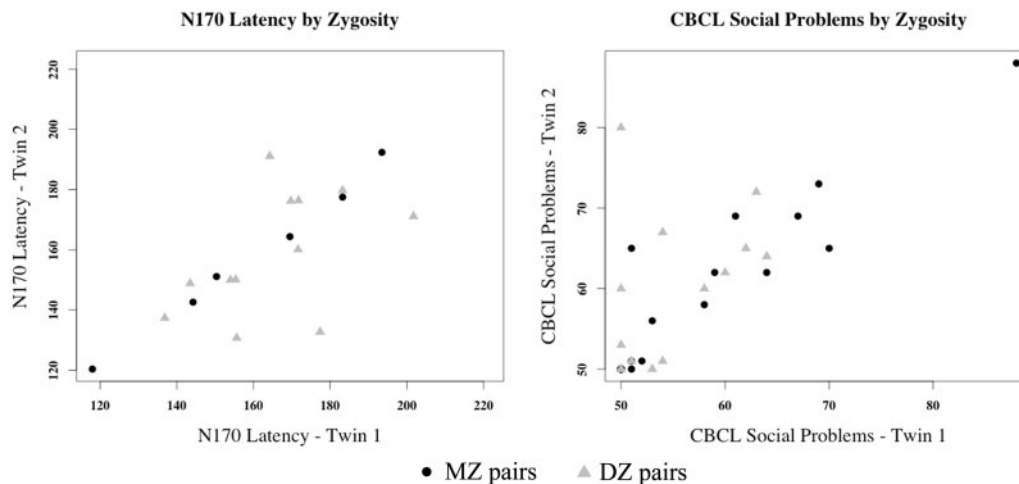


Fig. 4. ICCs for N170 latency and CBCL social problems.

Notes. Twin 1 and Twin 2 refer to first- and second-born twins, respectively.

neurotypical samples with no family history of ASD, our sample constitutes a somewhat different comparison group that could serve to attenuate group differences. Indeed, we observed much greater variability and range in measures assessing social skills and difficulties in our group without ASD than we would anticipate in a neurotypical comparison group, and all results should be interpreted with this consideration in mind.

Our findings also diverge from previous work indicating enhanced N170 amplitudes for inverted relative to upright faces (e.g. Rossion et al., 2000; Itier and Taylor, 2004; McPartland et al., 2004). Instead, we observed more negative amplitudes for upright faces than for inverted faces. Although this effect contrasts with much of the N170 literature with adults, it is consistent with a smaller body of work (e.g. Taylor et al., 2004; Hileman et al., 2011) documenting relatively larger N170 amplitudes to upright faces among child and adolescent participants, both with and without ASD. Our findings add to suggestions that the direction of orientation-related amplitude differences shifts over the course of development, with adult-like effects of inversion emerging during adolescence (Taylor et al., 2004).

Electrophysiological and behavioral measures of face processing were significantly correlated with social skills and social difficulties in our sample when participants with and without

ASD were considered together. Faster processing (i.e., faster P1 and more accurate processing (i.e., higher accuracy scores on holistic and memory tasks) were associated with better social skills and fewer social difficulties, in accordance with hypotheses. Interestingly, these associations emerged in the absence of correlations between P1 latency and behavioral indices of face processing (i.e. holistic face task and face memory). This may be due to the fact that these tasks draw upon a range of skills, including early attention (indexed in part by P1), memory and executive function. Although all of these would likely contribute to social functioning, the P1 response captures only a small component of these demands and thus might not appear to be correlated. Also surprising, we did not observe correlations between response amplitudes and social skills. To the extent that amplitude reflects neural effort, this pattern of association may suggest that successful social functioning relies more upon speed of face processing rather than neural effort. Indeed, social cues (e.g. facial expressions, changes in eyegaze) are typically fleeting and dynamic, and slowed processing of these cues could result in missed or inaccurate social inferences.

Although cross-sectional in nature, these relations are consistent with depictions of face processing as an important skill in the repertoire of social cognition and behavior (Dawson et al.,

2005) and may provide evidence of meaningful links between face processing and social functioning in everyday life. However, these findings are tempered by the fact that our diagnostic groups differed significantly on both P1 latency and measures of social functioning. This raises the possibility that correlations across the sample as a whole reflect those group differences rather than robust brain-behavior associations, particularly given that correlations were not significant within diagnostic groups. Thus these conclusions are tentative and await replication.

With regard to twin correspondence, we found strong correlations between twins on nearly all measures of interest, including P1 and N170 latency and amplitude, face processing tasks and social measures. Although strong correlations on parent-report measures could be due in part to the same parent reporting on both of their twins, the breadth and strength of our observed correlations also suggest shared developmental influences on twins' social behavior and face processing. For many variables, twin correspondence was similar for MZ and DZ pairs, suggesting that many of these influences on social development may be environmental in nature (e.g. family factors, peer groups, intrauterine environment), rather than strictly genetic. Twin similarity may have been especially strong in our sample because our analyses of twin correspondence were restricted to sex- and diagnosis-concordant pairs.

Despite high twin correspondence overall, we did find preliminary evidence of potential genetic influences on two indices related to social functioning—N170 latency to upright faces, and social difficulties as assessed with the CBCL. Our finding of higher MZ relative to DZ correlations for N170 latency is based on a rather small number of MZ twins, but is novel and provides the first support for heritability of N170 latency to faces. This finding also fits well with a previous finding of heritability in N170 amplitude to affective faces (Shannon et al., 2013). Given that heritability estimates often increase over the course of development (Beauchaine et al., 2008), future studies with adults with ASD may yield stronger support for N170 heritability.

We also found stronger MZ twin correspondence for CBCL Social Problems despite similar ICCs for our other measures of social skills and difficulties. Zygosity differences on the CBCL Social Problems subscale but not on the SRS subscales may be due to the nature of the difficulties the two measures capture. Although the SRS may tap more subtle social concerns (e.g. perception of social cues, emotional reciprocity), the CBCL may tap more blatant social difficulties (e.g. dependency on others, difficulty getting along with others) of which parents are more aware, allowing greater differentiation between twins. We also found support for heritability in social problems, but not social skills, suggesting that examining social difficulties as distinct from social skills may be valuable.

Limitations and future directions

Although our sample included both male and female participants, replication of our findings within a larger, sex-balanced twin sample will be important. Molecular genetics data suggest that the genetic basis of autism may differ by sex (Schellenberg et al., 2006), and domain-specific genetic influence may as well. Robinson et al. (2012) found evidence for sex differences in the heritability of individual ASD symptom domains, with particular differences in the area of social impairment. Furthermore, face processing and ERPs to faces have been shown to differ by sex, with differential links to social functioning in males and females (Coffman et al., 2015; Rhodes et al., 2013). As such,

balanced representation of male and female participants will be critical to elucidate patterns of heritability and corresponding genetic and environmental mechanisms.

Future efforts would also benefit from inclusion of a broader range of social skills. Tasks related to perspective-taking, imitation, joint attention and nonverbal communication, for example, would allow for finer distinctions of skill within the larger 'social skill' umbrella. It may be that finer grained analysis reveals additional patterns of twin correspondence. Similarly, the inclusion of observational and self-report measures would complement parent-report measures and more fully capture twins' social skills, difficulties and subjective experiences.

Conclusions

Our findings provide preliminary evidence of (i) differential P1 but similar N170 responding to faces among twins with and without ASD, (ii) tentative links between neural and behavioral face processing, and social functioning, and (iii) potential heritability of both neural speed in face processing and social difficulties. Taken together, these findings reinforce the importance of face processing, both in predicting meaningful social outcomes and in the search for potential genetic underpinnings in ASD.

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Supplementary data

Supplementary data are available at SCAN online.

Conflict of interest statement. None declared.

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