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Developmental and Individual Differences on the P1 and N170 ERP Components in Children with and without Autism

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Abstract

The P1 and N170 components, two event-related potentials sensitive to face processing, were examined in response to faces and vehicles for children with autism and typical development. P1 amplitude decreased, P1 latency decreased, and N170 amplitude became more negative with age. Children with typical development had larger P1 amplitudes for inverted faces than upright faces, but children with autism did not show this pattern. Children with autism had longer N170 latencies than children with typical development. Smaller P1 amplitudes and more negative N170 amplitudes for upright faces were associated with better social skills for children with typical development.

Keywords

N170; P1; face processing; autism; development; individual differences

INTRODUCTION

Face processing is a skill that appears early in development and is integral for subsequent social development. Individuals with autism have difficulty with face processing (Dawson, Webb, Carver, Panagiotides, & McPartland, 2004; Izard et al., 2001; Stormark & Braarud, 2004), but it is not clear whether this deficit comes online at an early perceptual stage or at a later social cognitive stage in face processing. In their recent review of the literature, Jeste and Nelson (2009) emphasize the integral role of Event Related Potentials (ERPs) in determining the stage at which a face processing deficit occurs. Due to their high temporal resolution, ERPs can be used to differentiate between early perceptual impairments and later social cognitive impairments.

In the present study, two ERP components that are reflective of the early stages of face processing were examined: the P1 and N170 components. These components were evaluated in response to 1) faces and vehicles and 2) upright faces and inverted faces in children with typical development and high functioning autism, ranging in age from 9 to 17 years old. We were particularly interested in examining developmental changes and diagnostic group differences on these ERP components.

Finally, we wanted to examine whether individual differences in the P1 and N170 ERP components were related to individual differences in social cognition and atypical social behaviors. Given that individuals with autism and typical development may have qualitatively different approaches to face processing, we further examined whether the pattern of associations between these measures differed by diagnostic group.

The P1 ERP Component

The P1 component is a positive ERP component that occurs approximately 100 ms after stimulus presentation. The P1 component appears to be sensitive to faces, as the amplitude for this component is significantly larger for face stimuli than most other types of stimuli (Itier & Taylor, 2004d). However, the P1 component is also affected by the participant's attention to the stimulus (Magnun, 1995) and task demands such as task load (Taylor, 2002), making the specificity of the P1 component to faces somewhat controversial.

The P1 component is greatly influenced by development. With age, the latency of the P1 component decreases, most likely reflecting maturation in the speed of stimulus processing (Itier & Taylor, 2004a; Taylor, Edmonds, McCarthy, & Allison, 2001). The amplitude of the P1 component also decreases with age, which may reflect synaptic pruning throughout childhood (Itier & Taylor, 2004a, 2004c; Taylor et al., 2001). The P1 component is sensitive to face inversion in children and adults with typical development, such that there is a longer latency and a larger amplitude to inverted faces than upright faces (Itier & Taylor, 2002; Itier & Taylor, 2004a, 2004b, 2004c). This inversion effect may be due to the disruption of configural processing for inverted faces, making it more difficult to identify a face as a face and thus requiring increased attention (Itier & Taylor, 2002).

Given the behavioral face processing impairments in individuals with autism, it is important to examine diagnostic group differences on the P1 component. O'Connor, Hamm, and Kirk (2005) found that adults with autism had a delayed P1 latency for faces compared to adults with typical development, but children with Asperger Syndrome and typical development did not differ on their P1 latency for faces. They further found that children, regardless of diagnostic group, had a larger P1 amplitude and a longer P1 latency than adults. O'Connor, Hamm, and Kirk (2007), however, reported that adults with and without Asperger Syndrome did not differ on P1 latency or amplitude.

In the current study, in order to extend both the developmental literature and the autism literature, we examined the P1 component in a sample of children with autism and typical development, ranging in age from 9 to 17 years old. We expected that P1 amplitude would be larger for: 1a) faces than vehicles, 1b) younger children than older children, and 1c) inverted faces than upright faces. We expected that P1 latency would be longer for: 2a) younger children than older children, 2b) inverted faces than upright faces, and 2c) children with autism than children with typical development. We also examined the relation between the P1 component and individual differences in social cognition and atypical social behaviors. Although we did not have a specific set of hypotheses regarding these individual differences, we expected that electrophysiological indicators of face processing would relate to behavioral indicators of social skills.

The N170 ERP Component

The N170 component is a negative ERP component that occurs approximately 170 ms after stimulus presentation (Eimer, 2000). In adults, the N170 is a face-specific, right-lateralized ERP component (Bentin, Allison, Puce, Perez, & McCarthy, 1996), although some researchers argue that the N170 is specific to expert processing, not face processing per se (Gauthier & Curby, 2005; Rossion, Curran, & Gauthier, 2002; Tanaka & Curran, 2001). In

adults with typical development, the N170 is delayed and enhanced for inverted compared to upright faces (Bentin et al., 1996; Rossion et al., 1999). As with the P1 component, inversion may disrupt the configural processing of a face, leading to delays in processing and enhanced neural activity due to increased processing difficulty (Rossion et al., 1999). While both the P1 and N170 components seem to be indicative of early face processing, it has been hypothesized that the P1 component reflects holistic face processing while the N170 component reflects the early structural encoding of a face (Cassia, Kuefner, Westerlund, & Nelson, 2006).

The literature on the N170 component in children has not thoroughly tested the specificity of this component to faces. However, the few research studies that have included non-social stimuli suggest that the N170 component is also face-specific in childhood (Taylor et al., 2001). There are many developmental changes in the N170 component. The latency of this component decreases and the amplitude becomes more negative with age (Batty & Taylor, 2006; Itier & Taylor, 2004a, 2004c; Taylor, McCarthy, Saliba, & Degiovanni, 1999). The N170 latency is delayed for inverted faces across all age groups while the N170 amplitude is only enhanced for inverted faces in older children and/or adults (Itier & Taylor, 2004a, 2004c).

Again, given that individuals with autism show behavioral impairments in face processing, it is important to consider diagnostic group differences on the N170 component. In adults with autism, the N170 latency is delayed for faces (McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; O'Connor et al., 2005, 2007). The latency of this component in autism appears to be less affected by face inversion, indicating that individuals with autism may be less sensitive to the configural properties of a face (McPartland et al., 2004). O'Connor et al. (2005) found that the N170 amplitude was attenuated for faces in adults with autism, but two other studies have not found diagnostic group differences for the N170 amplitude in adults (McPartland et al., 2004; O'Connor et al., 2007).

In addition to examining the N170 component in adults, O'Connor et al. (2005) also examined this component in children with autism and typical development, ranging in age from 9–15 years old. There were no diagnostic group differences on either latency or amplitude. While this study did not include age as a predictor of differences within the child sample, the N170 component was broadly compared across children with autism, children with typical development, adults with autism, and adults with typical development. They found that, regardless of diagnostic group, children had a longer N170 latency than adults. If age had been included as a predictor of differences within the child sample, it is likely that this study would have found developmental differences in the N170 component across children, as well.

While a handful of studies have examined diagnostic group differences on the N170 component, McPartland et al. (2004) extended this research by examining how individual differences within a diagnostic group relate to differences on the N170 component. They investigated how the N170 component specifically relates to individual differences in recognition memory for faces. For adolescents and adults with autism, better face recognition correlated with a longer N170 latency, whereas for adolescents and adults with typical development, better face recognition correlated with a shorter N170 latency. McPartland et al. (2004) interpreted this finding to show that individuals with autism have a qualitatively different approach to face processing. Their slow face processing speed may reflect the fact that individuals with autism are not expert face processors and need more time to accurately encode a face.

In the current study, in order to extend both the developmental literature and the autism literature, we examined the N170 component in a sample of children with autism and typical development, ranging in age from 9 to 17 years old. Additionally, we examined the relation of the N170 component to individual differences in atypical social behaviors and social cognition. We expected that N170 amplitude would be more negative for: 3a) faces than vehicles and 3b) older children than younger children. We expected that the effects of face orientation would depend on age such that: 3c) N170 amplitude for inverted faces would be more negative for older children than for younger children. Due to limited previous research and conflicting findings, we did not have a specific set of hypotheses regarding group differences or individual differences for N170 amplitude. We expected that N170 latency would be longer for: 4a) younger children than older children and 4b) inverted faces than upright faces. We expected that the effects of stimulus type and orientation would depend on diagnostic group such that: 4c) N170 latency for faces would be longer for individuals with autism than individuals with typical development and 4d) face orientation would have a greater effect on N170 latency for individuals with typical development than individuals with autism. Finally, with respect to individual differences, we expected that better social cognition and fewer atypical social behaviors would correlate with: 5a) a longer N170 latency for individuals with autism and 5b) a shorter N170 latency for individuals with typical development.

METHODS

Participants

Higher-functioning (verbal IQ ≥ 70) children and adolescents with autism (HFA) were recruited from the University of Miami / Nova Southeastern University Center for Autism and Related Disabilities. Comparison participants were recruited from Miami-Dade County public schools. A letter was sent home with the students, and interested parents could contact our research lab to set up an appointment. Two levels of screening were applied for both diagnostic groups: All participants were screened before coming into the lab and again after coming into the lab. In the initial screening, participants were excluded from further participation if they had a history of seizures, a genetic condition (such as Fragile X Syndrome), a reading level below the second grade, psychotic symptoms (such as hallucinations), a previously abnormal EEG, or if they were nonverbal. Participants with autism had to have a diagnosis of an Autism Spectrum Disorder (ASD) in accordance with DSM guidelines from a community mental health professional. Comparison participants could not have such a diagnosis.

Although participants with autism were already diagnosed with an ASD, we verified this diagnosis in the lab. Participants with autism were required to meet a cutoff score of 7 on the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, Dilavore, & Risi, 1999) and a cutoff score of 13 on the Social Communication Questionnaire (SCQ; Berument, Rutter, Lord, Pickles, & Bailey, 1999). Corsello et al. (2007) showed that the ADOS and the SCQ together have good sensitivity and specificity in identifying individuals with and without autism. Given that participants already had an ASD community diagnosis, participants who met the cutoff score on one measure and were within one point of the cutoff score on the other measure were also included in the sample. Comparison participants were excluded from participation in the study if they received a score of 7 or greater on the ADOS or received a score of 13 or greater on the SCQ. Additionally, both HFA and comparison participants were excluded from the study if they had a verbal IQ less than 70, as assessed by the Wechsler Intelligence Scale for Children – IV (WISC-IV; Williams, Weiss, & Rolfhus, 2003a, 2003b) Verbal Comprehension Index.

The initial sample included 32 HFA participants and 25 comparison participants. Five children with autism were excluded from the final sample: One child did not meet criteria for autism on the SCQ, 2 children did not meet criteria for autism on the ADOS, 1 child was unable to finish the protocol, and 1 child had incomplete data due to technical difficulties during data collection. Three comparison children who met criteria for autism on the ADOS were also excluded from the final sample. Therefore, the final sample included 27 HFA participants (23 males and 4 females) and 22 comparison participants (18 males and 4 females).

Table 1 presents demographic and descriptive information on participants. The groups did not differ on age, $t(47) = -1.55$, $p = 0.13$, verbal IQ, $t(47) = -1.80$, $p = 0.08$, performance IQ, $t(47) = 0.60$, $p = 0.55$, or gender distribution, $\chi^2(1, N = 49) = 0.10$, $p = 0.75$. The ethnic distribution for the sample was: 59.2% Hispanic; 26.5% Caucasian, Non-Hispanic; 6.1% Black, Non-Hispanic; 6.1% mixed Hispanic; and 2.0% no response.

Measures

Cognitive

Wechsler Intelligence Scale for Children – IV: Participants completed an abbreviated version of the Wechsler Intelligence Scale for Children – IV (WISC-IV; Williams et al., 2003a, 2003b). The Vocabulary Scale and the Similarities Scale of the Verbal Comprehension Index (VCI) were administered, and the Block Design Scale and the New Matrix Reasoning Scale of the Perceptual Reasoning Index (PRI) were administered. In this study, the WISC-IV VCI was used to ensure that all study participants had a verbal IQ of 70 or greater.

Autistic Symptoms and Atypical Social Behaviors

Autism Diagnostic Observation Schedule: Participants were administered the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1999). The ADOS is a semi-structured observational assessment that examines language and communication, reciprocal social interaction, imagination and creativity, and restricted and repetitive behaviors and interests in order to assess symptoms of pervasive developmental disorders. The ADOS is divided into four age-appropriate modules; participants in this study either received Module 3 or Module 4. In this study, the ADOS was used to discriminate between participants with autism and typical development. In addition, the ADOS Social Interaction Score was used as an indicator of individual differences in atypical social behaviors.

Social Communication Questionnaire: Parents of participants completed the Social Communication Questionnaire (SCQ; Berument et al., 1999). This questionnaire was developed from the forty critical items of the Autism Diagnostic Interview, and it focuses on social interaction, communication, and repetitive and stereotyped behaviors. In this study, the SCQ was used to discriminate between participants with autism and typical development. In addition, the SCQ Social Interaction Score was used as an indicator of individual differences in atypical social behaviors.

Social Cognition

Children's Eyes Test: Participants completed the Children's Eyes Test (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). In this test, participants viewed 28 pictures of the eye region of the face. They selected one of four affect words that best described what the person in the picture was thinking or feeling. The number of pictures in which the participant correctly identified the affect is the Children's Eyes Test Total. In this study, the

Children's Eyes Test Total was used as an indicator of individual differences in social cognition.

Strange Stories Task: Participants completed the Strange Stories Task (Happé, 1994). In this task, participants read a series of 12 stories and then answered a few questions about each story. The stories assess the participant's mentalizing ability by featuring specific social situations or sayings, such as a lie, sarcasm, or figure of speech. The participant was first asked a Reality Question to confirm that they understood the events of the story. Second, the participant was asked a Justification Question to explain why the events of the story unfolded in that particular manner. The number of Reality and Justification Questions that the participant answered correctly is the Strange Stories Total. In this study, the Strange Stories Total was used as an indicator of individual differences in social cognition.

Stimuli

The stimuli for the EEG face processing task were gray-scale photographs of vehicles and faces. These photographs were matched on size and background color (white). The face stimuli were taken from the NimStim Face Stimulus Set (Tottenham et al., 2009). Four blocks of stimuli were randomly presented to participants: upright faces, inverted faces, upright vehicles, and inverted vehicles (see Figure 1). One hundred and twenty photographs were presented within each stimulus block. Each face stimulus block included thirty pictures of angry, fearful, happy, and neutral faces. The face stimuli were the stimuli of interest; the vehicle stimuli were presented as a comparison to the face stimuli. Each photograph was presented for 500 ms, followed by a blank screen for 500 ms. E-Prime software was used to control the timing parameters.

Procedure

Before EEG data collection, a 128-lead Geodesic sensor net (Electrical Geodesics, Inc., USA) was dipped into a potassium-chloride electrolyte solution and fitted to the participant's head. The electrodes covered the scalp from the left ear to the right ear and from the nasion to the inion. Impedances were kept below 50 k Ω . EEG was recorded continuously.

During the face processing task, participants were seated approximately 50 cm from the computer monitor used for stimulus presentation. Participants were asked to count the number of vehicles facing left during the vehicle blocks and to count the number of female faces during the face blocks. At the end of each block, participants reported the total number of stimuli that they had counted.

The present study employs a blocked stimulus presentation scheme in an effort to ensure that participants are processing the stimuli in their entirety. By asking participants to respectively count the number of vehicles facing left and the number of female faces, holistic stimulus processing is encouraged. Other studies have employed a randomized stimulus presentation scheme and asked participants to count and attend to a rare target stimulus. However, this presentation scheme does not ensure that participants are holistically processing non-target stimuli. Participants may simply look for a visual detail that is indicative of the target stimulus, and if that detail is not found, they may not further process the stimulus. Thus, the current study uses a blocked stimulus presentation scheme in an effort to encourage holistic stimulus processing.

The EEG signal was amplified (x1000) and filtered (0.1 Hz high-pass filter and 100 Hz elliptical low-pass filter) using a preamplifier system. The conditioned signal was multiplexed and digitized at 250 Hz using an analog-to-digital converter and a Macintosh

computer. All 128 channels were continuously recorded and streamed to the computer's hard drive. A Dell computer, interfaced and synchronized via serial port, used e-Prime software to generate the stimuli. Stimulus onset and offset were recorded in order to later segment the data. The Cz electrode was used as the reference during data collection, and data were re-referenced to an average reference after data collection.

Data Editing and Reduction

Data was digitally filtered at a low-pass of 30 Hz to reduce artifacts caused by environmental noise. Data were segmented into 4 categories: upright faces, upright vehicles, inverted faces, and inverted vehicles. Artifact detection was conducted on all electrode channels. An electrode channel was marked bad if the fast average amplitude of the channel exceeded 200 μV , if the differential average amplitude of the channel exceeded 100 μV , if the channel had zero variance, or if the channel had been marked bad in over 25% of the trials. Across all categories, 74–76% of trials did not have any bad channels, 16–18% of trials had 1 (out of 128) bad channels, 4–5% of trials had 2 (out of 128) bad channels, 2–4% of trials had 3–5 (out of 128) bad channels, and 1% of trials had more than 5 (out of 128) bad channels. The data in bad channels were replaced with data interpolated from nearby good channels, using spherical splines (Electrical Geodesics, Inc., 2004). The spherical splines technique of bad channel replacement is based on the premise that scalp locations close to one another have similar voltage values and the voltage value of a given scalp location can be inferred from nearby electrode sites, given adequate electrode density (Fletcher, Kussmaul, & Mangun, 1996).

A trial was rejected if it contained more than 16 bad channels. In addition, all segments were manually reviewed for artifacts and/or eye blinks. If any artifacts were detected during manual review, the segment was rejected. For participants with autism and comparison participants respectively, an average of 5% / 3% of trials were rejected for the upright faces condition, 7% / 5% of trials for the upright vehicles condition, 8% / 4% of trials for the inverted faces condition, and 6% / 3% of trials for the inverted vehicles condition. A repeated measures ANOVA was conducted on the number of rejected trials, with condition as the within-groups factor and diagnostic group as the between-groups factor. There was no significant effect of condition, $F(3, 141) = 1.95$, $p = 0.12$, $\eta^2_p = 0.04$, or diagnostic group, $F(1, 47) = 2.71$, $p = 0.11$, $\eta^2_p = 0.06$, and there was no significant interaction between condition and diagnostic group, $F(3, 141) = 0.29$, $p = 0.83$, $\eta^2_p < 0.01$, on the number of rejected trials. After trial rejection, data were averaged by condition for each participant. At least 75 trials of artifact-free data were required for each condition. The data were re-referenced to an average reference and baseline corrected, with the baseline interval specified as 100 ms before the sample.

Finally, values for P1 amplitude, P1 latency, N170 amplitude, and N170 latency were extracted from each average data segment. For the P1 component, four electrodes over the left occipital scalp (65, 66, 70, and 71) and four electrodes over the right occipital scalp (84, 85, 90, and 91) were analyzed (see Figure 2). These electrode sites were selected to match the electrode sites in O'Connor et al. (2005). The maximum amplitude value and the latency to the first positive peak 79–139 ms after stimulus presentation was identified for each electrode site. For the N170 component, six electrodes over the left lateral posterior scalp (58, 59, 64, 65, 69, and 70) and six electrodes over the right lateral posterior scalp (90, 91, 92, 95, 96, and 97) were analyzed (see Figure 2). These electrode sites were selected to match the electrode sites in McPartland et al. (2004). The minimum amplitude value and the latency to the first negative peak 143–231 ms after stimulus presentation were identified for each electrode site. For both P1 and N170, the extracted amplitude and latency values were then averaged across left hemisphere and right hemisphere sites.

RESULTS

The grand averaged P1 and N170 ERP waveforms for children with autism and typical development, regardless of age, and younger children and older children, regardless of diagnostic group, are presented in Figure 3.

Group Differences

Two sets of repeated measures ANCOVAs were conducted on P1 amplitude, P1 latency, N170 amplitude, and N170 latency. The purpose of the first set of ANCOVAs was to examine differences in processing face and vehicle stimuli, so stimulus type (faces vs. vehicles) was a within-subjects factor. The purpose of the second set of ANCOVAs was to examine differences in processing upright and inverted faces, so face orientation (upright vs. inverted) was a within-subjects factor. For both sets of ANCOVAs, diagnostic group (autism vs. typical development) was a between-subjects factor and age and verbal IQ were continuous covariates. Since age was a variable of theoretical interest, it was retained as a covariate in the analysis regardless of whether its effect was significant. Verbal IQ was only retained in the analysis if it had a significant effect.

The ANCOVA assumption of parallel regression slopes was examined by testing for an interaction between diagnostic group and age or diagnostic group and verbal IQ. The interaction terms were not significant for any of the ANCOVA analyses. Thus, the assumption of parallel regression slopes was met, and the interaction terms were removed from further analyses.

P1 Amplitude—Table 2 shows the mean values for P1 amplitude. For the analysis comparing P1 amplitude for faces and vehicles, there was a main effect of stimulus type, $F(1, 46) = 6.27, p = 0.02, \eta^2_p = 0.12$, and a main effect of age, $F(1, 46) = 23.36, p < 0.01, \eta^2_p = 0.34$. These main effects were qualified by a significant two-way interaction between stimulus type and age, $F(1, 46) = 7.40, p = 0.01, \eta^2_p = 0.14$. Post hoc probing was conducted to interpret the stimulus type by age interaction effect. The marginal means for stimulus type were estimated at 11.28 years (one standard deviation below the mean age), 13.79 years (the mean age), and 16.30 years (one standard deviation above the mean age), as suggested by Aiken and West (1991). The marginal means at each age were then compared using *t*-tests. For younger children, there was a significant effect of stimulus type, $t(46) = 2.64, p = 0.01$, such that the amplitude for vehicles was larger than the amplitude for faces. At the mean age, there was not a significant effect of stimulus type, $t(46) = 1.35, p = 0.18$. For older children, there was a significant effect of stimulus type, $t(46) = 5.33, p < 0.01$, such that the amplitude for faces was larger than the amplitude for vehicles. See Figure 4. In sum, the P1 amplitude for vehicles decreased more steeply with age than the P1 amplitude for faces.

For the analysis comparing P1 amplitude for upright faces and inverted faces, there was a main effect of age, $F(1, 46) = 18.28, p < 0.01, \eta^2_p = 0.28$, such that P1 amplitude decreased with age. There was also a significant two-way interaction between orientation and diagnostic group, $F(1, 46) = 4.95, p = 0.03, \eta^2_p = 0.10$. Post hoc within group analyses revealed that the P1 amplitude was larger for inverted faces than upright faces for children with typical development, $F(1, 20) = 8.60, p = 0.01, \eta^2_p = 0.30$, but not for children with autism, $F(1, 25) = 0.72, p = 0.40, \eta^2_p = 0.03$. See Figure 5.

P1 Latency—Table 2 shows the mean values for P1 latency. For the analysis comparing P1 latency for faces and vehicles, there was a main effect of age, $F(1, 45) = 6.69, p = 0.01, \eta^2_p = 0.13$, such that latency decreased with age, and a main effect of verbal IQ, $F(1, 45) = 6.91, p = 0.01, \eta^2_p = 0.13$, such that children with a higher verbal IQ had a longer latency. For the analysis comparing P1 latency for upright faces and inverted faces, there was again a

main effect of age, $F(1, 45) = 6.95$, $p = 0.01$, $\eta^2_p = 0.13$, such that latency decreased with age, and a main effect of verbal IQ, $F(1, 45) = 8.44$, $p = 0.01$, $\eta^2_p = 0.16$, such that children with a higher verbal IQ had a longer latency.

N170 Amplitude—Table 3 shows the mean values for N170 amplitude. For the analysis comparing N170 amplitude for faces and vehicles, there was a main effect of age, $F(1, 46) = 14.34$, $p < 0.01$, $\eta^2_p = 0.24$, such that N170 amplitude became more negative with age. For the analysis comparing N170 amplitude for upright faces and inverted faces, there was a main effect of orientation, $F(1, 46) = 8.60$, $p = 0.01$, $\eta^2_p = 0.16$, and a main effect of age, $F(1, 46) = 10.78$, $p < 0.01$, $\eta^2_p = 0.19$. These main effects were qualified by a significant two-way interaction between orientation and age, $F(1, 46) = 4.55$, $p = 0.04$, $\eta^2_p = 0.09$. Post hoc probing was conducted to interpret the orientation by age interaction effect. The marginal means for orientation were estimated at 11.28 years (one standard deviation below the mean age), 13.79 years (the mean age), and 16.30 years (one standard deviation above the mean age), as suggested by Aiken and West (1991). The marginal means at each age were then compared using t -tests. For younger children, $t(46) = 10.01$, $p < 0.01$, at the mean age, $t(46) = 6.89$, $p < 0.01$, and for older children, $t(46) = 3.76$, $p < 0.01$, there was a significant effect of orientation such that the amplitude for upright faces was more negative than the amplitude for inverted faces. However, the amplitude for inverted faces decreased more steeply with age than the amplitude for upright faces. See Figure 6.

These analyses were repeated, controlling for P1 amplitude as a covariate. The results were similar, with P1 amplitude usurping the effects of age in the analyses. Given the strong relation between P1 amplitude and age and the shared method variance between P1 amplitude and N170 amplitude (i.e., variance that can be attributed to the ERP measurement method, rather than a particular construct of interest), it seems that P1 amplitude was simply acting as a proxy variable for age. Since age is the theoretically more meaningful variable, P1 amplitude was not retained in the analyses as a covariate.

N170 Latency—Table 3 shows the mean values for N170 latency. For the analysis comparing N170 latency for faces and vehicles, there was a significant main effect of diagnostic group, $F(1, 46) = 5.86$, $p = 0.02$, $\eta^2_p = 0.11$, such that children with autism had a longer N170 latency than children with typical development. For the analysis comparing N170 latency for upright faces and inverted faces, there were no significant effects.

Individual Differences

The ADOS Social Interaction Score and SCQ Social Interaction Score were used as indicators of individual differences in atypical social behaviors, and the Strange Stories Total and Children's Eyes Test Total were used as indicators of individual differences in social cognition. Table 1 shows the range, mean, and standard deviation for these measures. Six participants with autism had incomplete data for both the Strange Stories Task and the Children's Eyes Test. Two participants with typical development had incomplete data for the Strange Stories Task. In order to detect outliers, z -scores across the whole sample were computed for these measures. Participants with a z -score greater than $|3|$ were removed from further analyses. One participant in the autism group was removed from further Strange Stories and Children's Eyes Test analyses.

The ADOS Social Interaction Score and the SCQ Social Interaction Score were highly correlated, $r(49) = 0.66$, $p < 0.01$, so these scores were averaged together to create a composite Atypical Social Behavior Score. Similarly, the Strange Stories Total and the Children's Eyes Test Total were highly correlated, $r(40) = 0.34$, $p = 0.03$, so these scores were averaged together to create a composite Social Cognition Score. Skewness and kurtosis

statistics were checked for composite variables within both diagnostic groups; all statistics were indicative of normal distributions. Partial correlations, controlling for age and verbal IQ, between ERP measures for upright faces (P1 amplitude, P1 latency, N170 amplitude, and N170 latency) and the Atypical Social Behavior and Social Cognition Scores were conducted separately for children with autism and typical development. Table 4 shows the partial correlations.

For children with autism, none of the correlations were significant. For children with typical development, 3 out of 8 correlations were significant: The Atypical Social Behavior Score was significantly and positively correlated with P1 amplitude, $r(18) = 0.68$, $p < 0.01$, and N170 amplitude, $r(18) = 0.56$, $p = 0.01$, such that more atypical social behaviors were associated with a higher P1 amplitude and a less negative N170 amplitude, and the Social Cognition Score was significantly and negatively correlated with P1 amplitude, $r(18) = -0.50$, $p = 0.02$, such that better social cognition was associated with a lower P1 amplitude.

Summary of Results

P1 amplitude decreased, P1 latency decreased, and N170 amplitude became more negative with age. For P1 amplitude, there was a significant interaction between stimulus type and age, such that the amplitude for vehicles decreased more steeply with age than the amplitude for faces. For P1 amplitude, there was also a significant interaction between orientation and diagnostic group, such that only individuals with typical development had a larger P1 amplitude for inverted faces than upright faces. For P1 latency, there was a main effect of verbal IQ, such that children with a higher verbal IQ had a longer latency. For N170 amplitude, there was a significant interaction between orientation and age, such that the amplitude for inverted faces decreased more steeply with age than the amplitude for upright faces. There was a main effect of diagnostic group on N170 latency, such that individuals with autism had a longer N170 latency than individuals with typical development. Finally, for individuals with typical development, smaller P1 amplitudes were associated with fewer atypical social behaviors and better social cognitive skills and more negative N170 amplitudes were associated with fewer atypical social behaviors. For individuals with autism, there were no relations between the ERP components and atypical social behaviors and social cognition.

DISCUSSION

Developmental Effects

The results of this study clearly show that, regardless of diagnostic group, chronological age has a large impact on electrophysiological correlates of face processing, specifically the P1 and N170 ERP components. In this study, P1 amplitude and P1 latency significantly decreased with age, and N170 amplitude became significantly more negative with age. In addition, there was a trend for N170 latency to decrease with age, and it is likely that this trend would have reached significance with a larger sample size. This developmental effect on the P1 and N170 ERP components is consistent with previous literature (Batty & Taylor, 2006; Itier & Taylor, 2004a, 2004c; Taylor et al., 1999; Taylor, Batty, & Itier, 2004).

While both the P1 and N170 amplitude became more negative with age, it is important to be cautious in interpreting the increased negativity of the N170 amplitude. Some of the change in amplitude for N170 may have been due to carryover effects from the change in amplitude for P1, since the P1 component immediately precedes the N170 component. When P1 amplitude was included as a covariate in the analyses for N170 amplitude, P1 amplitude did have a significant effect on the analyses. However, given that P1 amplitude appeared to be acting as a proxy variable for age, chronological age was determined to have a significant

influence on both the P1 and N170 components. Future studies should more fully consider the possibility of carryover effects from the P1 amplitude to the N170 amplitude to determine whether such effects exist and if so, how they affect the interpretation of the N170 component.

Interestingly, since the P1 component is positive, a decrease in amplitude for this component results in a smaller ERP. Conversely, since the N170 component is negative, a decrease in amplitude for this component results in a larger ERP. Thus, with age, the P1 component is becoming smaller, while the N170 component is becoming larger. These changes likely reflect both structural and functional neurodevelopmental changes. For example, it has been hypothesized that the decrease in amplitude of the P1 component across childhood is due in part to synaptic pruning (Itier & Taylor, 2004c). Functionally, the P1 component may reflect processing effort while the N170 component more closely reflects processing expertise, or some combination of processing effort and expertise. The increased neural efficiency associated with pruning and the accumulation of face processing experience may contribute to more automatic and less effortful face processing, allowing for greater expertise in face processing. Together these structural and functional changes may lead to smaller amplitude P1 responses, indicative of more automatic and less effortful face processing, and larger amplitude N170 responses, indicative of greater expertise in face processing. Following this same logic, the P1 component may be a more sensitive measure of face processing in childhood, given that children are actively undergoing synaptic pruning to establish more automatic and less effortful face processing, and the N170 component may be a more sensitive measure of face processing in adulthood, given that adults are developing and exercising their face processing expertise.

With age, the child face processing ERP components began to more closely resemble the adult face processing ERP components. For adults, the P1 component is more positive for faces than a variety of non-face stimuli, including mushrooms, flowers, houses, tools, road signs, and textures (Itier & Taylor, 2004d). In this study, younger children actually showed more positive P1 amplitudes for vehicles than faces. The P1 amplitude for vehicles decreased more steeply with age than the P1 amplitude for faces, thus it was not until adolescence that the adult pattern of a more positive P1 amplitude for faces than vehicles was apparent. Again these developmental changes likely reflect a combination of structural and functional changes in the processes underlying face processing. Given the complexity of information conveyed in faces (e.g., gender, identity, affect, age) compared to objects, faces may continue to elicit more thorough processing than objects, including vehicles, across development. These differences in stimulus complexity may contribute to differences in rates of developmental change at both structural (i.e., synaptic pruning) and functional (i.e., processing effort) levels, which together contribute to the differential rates of change in P1 amplitude by stimulus type observed in the current study. In the current study, the P1 component has reached its adult form by late adolescence, consistent with our hypothesis that the P1 component may show more variability and thus may more sensitively index face processing differences in children.

Similarly, for adults, the N170 component is more negative for inverted faces than upright faces (Rossion et al., 1999). In this study, younger children showed more negative N170 amplitudes for upright faces than inverted faces. The N170 amplitude for inverted faces decreased more steeply with age than the N170 amplitude for upright faces. Thus, while older children did not yet show the adult pattern of having more negative N170 amplitudes for inverted faces than upright faces, there was a general trend toward this result. If this study had included older participants, such as participants in their late teens or young adults, it is likely that this result would have been realized. By older childhood, the N170 amplitude was growing increasingly closer to its adult form, but it had not yet reached its adult form. If

the N170 component is a more sensitive measure of face processing for adults, it makes sense that this component had not reached its adult form by adolescence.

Diagnostic Group Effects

Consistent with previous behavioral literature (Hobson, Ouston, & Lee, 1988), individuals with autism seem to be less sensitive to face inversion than individuals with typical development. Individuals with typical development had larger P1 amplitudes for inverted faces compared to upright faces, while individuals with autism did not have differential P1 amplitudes for upright and inverted faces. Individuals with typical development may process faces holistically, thus they have more difficulty processing inverted faces than upright faces (Freire, Lee, & Symons, 2000). Individuals with autism may process faces in a piecemeal fashion, thus they are less affected by face inversion (Happé, 1999). If the P1 component is indicative of processing effort, it follows that this component would be larger for inverted faces in individuals with typical development, but not individuals with autism.

Individuals with autism may also take longer to process stimuli than individuals with typical development. Individuals with autism had longer N170 latencies than individuals with typical development. However, this delayed latency was apparent across both faces and vehicles; it was not specific to face stimuli. It is not uncommon for ERPs to be delayed in individuals with autism compared to individuals with typical development (Henderson et al., 2006; Jansson-Verkasalo et al., 2003; Jansson-Verkasalo et al., 2005; Townsend et al., 2001), so this delayed latency effect may be indicative of a slower general processing speed.

Research has demonstrated cortical underconnectivity in autism (Just, Cherkassky, Keller, Kana, & Minshew, 2007), and this underconnectivity may explain why individuals with autism show delayed ERPs. Reduced connectivity makes it difficult for cortical areas to quickly exchange information with one another. Complex information processing is particularly dependent on the efficient communication of different brain regions, thus delayed ERPs may be particularly apparent in complex information processing tasks, such as the processing of complex visual stimuli.

Much of the research in the autism literature has shown that individuals with autism have impairments in face processing compared to individuals with typical development. However, more recent research suggests that the face processing abilities of individuals with autism have been underestimated (e.g., Adolphs, Sears, & Piven, 2001; Castelli, 2005; Grossman, Klin, Carter, & Volkmar, 2000; Jemel, Mottron, & Dawson, 2006). In particular, studies that have enhanced the attention or motivation of participants with autism while attending to faces (e.g., Hadjikhani et al., 2004; Pierce, Haist, Sedaghat, & Courchesne, 2004) have shown evidence of intact face processing in autism. This study, by demonstrating that development has a larger impact on the P1 and N170 ERP components than diagnostic group, provides electrophysiological evidence to further bolster the theory that face processing deficits in individuals with autism may be overestimated in the literature.

Other Effects

Individuals with a higher verbal IQ had a longer P1 latency, which may suggest that these individuals are processing the stimuli more fully than individuals with a lower verbal IQ. While the discrepancy in latency between individuals with autism and typical development is likely due to a slower processing speed in individuals with autism, the discrepancy in latency between individuals with a high verbal IQ and a low verbal IQ is likely due to more extensive stimulus processing in individuals with a high verbal IQ.

Also, it is worth noting that the grand average N170 component in this study had a positive amplitude, rather than a negative amplitude. Although the N170 component was characterized by a downward peak, this peak often did not extend into the negative amplitude region. The P1 component in this study was very large; thus, the N170 component may not have reached a negative amplitude value due to the large positivity of the preceding P1 component. Also, there is a significant developmental influence on the N170 component, such that this component becomes increasingly more negative with age.

The N170 component in this study was not differentially responsive to faces compared to vehicles. In the literature on adults, the N170 component has larger amplitudes for faces compared to non-face stimuli (Bentin et al., 1996), but this observation has not been rigorously evaluated in children. The results of this study suggest that the N170 may become specific to faces over time, as face processing expertise develops. Further research is needed to determine whether the N170 is specific to faces in children, or whether the N170 become specific to faces as individuals develop face processing expertise.

Relations between Face Processing ERPs and Atypical Social Behavior & Cognition

For individuals with typical development, smaller P1 amplitudes were associated with better social cognitive skills, and smaller P1 amplitudes and more negative N170 amplitudes were associated with fewer atypical social behaviors. These associations were over and above the effects of age and verbal IQ. Individuals who devote relatively greater effort to face processing, as indicated by large P1 amplitudes, and have less face processing expertise, as indicated by less negative N170 amplitudes, tend to have less developed social skills and show more atypical social behaviors. This may reflect relatively inefficient neural processing which translates into less fluid and more effortful reciprocal social interactions. Given that these analyses are correlational, it is not clear whether face processing influences the development of social skills or whether social skills facilitate better face processing. A longitudinal design is needed to better understand the direction of this relation.

While individuals with typical development showed strong associations between the ERP measures and atypical social behaviors and social cognition, individuals with autism did not show associations between these measures. The ERP measures may not properly index face processing ability in the autism group. The ERP measures may instead index general processing ability for the autism group, in which case these measures wouldn't show associations with atypical social behaviors or social cognition.

When McPartland et al. (2004) examined individual differences in the N170 component, they found conceptually similar results for individuals with typical development but different results for individuals with autism. For individuals with typical development, shorter N170 latencies were associated with better face recognition in the McPartland et al. (2004) study, and smaller P1 amplitudes were associated with better social cognition in the current study. These findings can be interpreted similarly: Less cognitive effort, whether indicated by a shorter latency or a smaller amplitude, is associated with better social skills in individuals with typical development. For individuals with autism, longer N170 latencies were associated with better face recognition in the McPartland et al. (2004) study, and no associations were found in the current study. The McPartland et al. (2004) study specifically examined the ERP measures in relation to face recognition while the current study more broadly examined the ERP measures in relation to social skills. For individuals with autism, these associations may be specific to face recognition ability or may be specific to the face recognition task used by McPartland et al. (2004); these associations may not generalize more broadly to social skills.

Limitations and Future Directions

Neural circuitry specific to face processing changes with age (Gathers, Bhatt, Corbly, Farley, & Joseph, 2004; Passarotti, Paul, & Stiles, 2001), so the electrode sites that would have best captured the P1 and N170 ERP responses for young children may have been different from the electrode sites that would have best captured the P1 and N170 ERP responses for older adolescents. Although we tried to select electrode sites that would best capture these ERP responses across all ages, it is possible that the ERP responses weren't captured as clearly in the youngest and oldest children. Future research should consider developmental changes in the distribution and localization of ERP responses.

The results of this study are limited by a relatively small sample size and incomplete matching. Although there were no significant differences between the autism and typical development group on age, verbal IQ, performance IQ, or gender, the typical development group tended to be older and have a higher verbal IQ than the autism group. In the future, it would be better to have more closely matched groups, to ensure that differences due to diagnostic group can be clearly differentiated from differences due to age and IQ.

The results of this study underscore the importance of development, regardless of diagnostic group, on face processing; face processing is clearly an ability that continues to evolve and mature until adulthood. Also, these results suggest that individuals with autism and typical development do not have stark differences in face processing at an early age; rather, these diagnostic group differences may evolve over time. As individuals with typical development grow older, they develop expertise in face processing. Individuals with autism may be somewhat stagnant in their development of face processing expertise, thus the gap in face processing ability between these two groups may grow progressively larger with time. The results of this study are consistent with O'Connor et al. (2005), wherein developmental effects were a more salient predictor of the P1 and N170 components than diagnostic group effects and wherein more diagnostic group differences were found in adults than in children. Future research should further investigate the interplay between diagnostic group and chronological age on face processing ability.

While most of the face processing literature focuses on the N170 component, the results of this study suggest that the P1 component may be particularly important to consider in childhood. A unique contribution of this study is the examination of the P1 ERP component as it relates to face processing in childhood. Future studies should further research the P1 component in development and empirically examine the possibility that the P1 component is a more sensitive indicator of face processing in children, while the N170 component is a more sensitive indicator of face processing in adults.

Additionally, future studies should be designed to investigate the differential conceptual underpinnings of the P1 and N170 ERP components. In this study, we've hypothesized that the P1 component is indicative of processing effort while the N170 component is indicative of processing expertise. However, this is only one interpretation of the data and alternative interpretations of the data may exist. In particular, it may be important to consider how intrinsic interest in the stimuli and motivation to attend to the stimuli affect the amplitudes of the P1 and N170 components. Future research should develop experimental designs to test the role of interest and motivation on the P1 and N170 components.

Finally, future studies should continue to examine how the P1 and N170 ERP components relate to individual differences in social skills. In particular, it is unclear how these components relate to individual differences in social skills in autism. Furthermore, longitudinal studies are needed to determine the directionality of this relation: Better face

processing may lead to more adept social skills, or conversely more adept social skills may lead to better face processing.

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REFERENCES

- Adolphs R, Sears L, Piven J. Abnormal processing of social information from faces in autism. *Journal of Cognitive Neuroscience*. 2001; 13(2):232–240. [PubMed: 11244548]
- Aiken, L.; West, S. *Multiple Regression: Testing and Interpreting Interactions*. Newbury Park, CA: Sage Publications, Inc; 1991.
- Baron-Cohen S, Wheelwright S, Hill J, Raste Y, Plumb I. The “Reading the Mind in the Eyes” Test Revised Version: A study with normal adults, and adults with Asperger Syndrome or high functioning autism. *Journal of Child Psychology and Psychiatry*. 2001; 42:241–251. [PubMed: 11280420]
- Batty M, Taylor MJ. The development of emotional face processing during childhood. *Developmental Science*. 2006; 9:207–220. [PubMed: 16472321]
- Bentin S, Allison T, Puce A, Perez E, McCarthy G. Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience*. 1996; 8:551–565. [PubMed: 20740065]
- Berument S, Rutter M, Lord C, Pickles A, Bailey A. Autism screening questionnaire: Diagnostic validity. *British Journal of Psychiatry*. 1999; 175:444–451. [PubMed: 10789276]
- Cassia V, Kuefner D, Westerlund A, Nelson C. A behavioural and ERP investigation of 3-month-olds’ face preferences. *Neuropsychologia*. 2006; 44:2113–2125. [PubMed: 16368116]
- Castelli F. Understanding emotions from standardized facial expressions in autism and normal development. *Autism*. 2005; 9(4):428–449. [PubMed: 16155058]
- Corsello C, Hus V, Pickles A, Risi S, Cook E, Leventhal B, et al. Between a ROC and a hard place: Decision making and making decision about using the SCQ. *Journal of Child Psychology and Psychiatry*. 2007; 48:932–940. [PubMed: 17714378]
- Dawson G, Webb SJ, Carver L, Panagiotides H, McPartland J. Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion. *Developmental Science*. 2004; 7:340–359. [PubMed: 15595374]
- Eimer M. Effects of face inversion on the structural encoding and recognition of faces: Evidence from event-related brain potentials. *Cognitive Brain Research*. 2000; 10:145–158. [PubMed: 10978702]
- Electrical Geodesics, Inc. *Net Station Waveform Tools: Technical Manual*. Eugene: Electrical Geodesics, Inc; 2004.
- Fletcher EM, Kussmaul CL, Mangun GR. Estimation of interpolation errors in scalp topographic mapping. *Electroencephalography and Clinical Neurophysiology*. 1996; 98:422–434. [PubMed: 8647046]
- Freire A, Lee K, Symons LA. The face-inversion effect as a deficit in the encoding of configural information: Direct evidence. *Perception*. 2000; 29:159–170. [PubMed: 10820599]
- Gathers AD, Bhatt R, Corbly CR, Farley AB, Joseph JE. Developmental shifts in cortical loci for face and object recognition. *Neuroreport: For Rapid Communication of Neuroscience Research*. 2004; 15:1549–1553.
- Gauthier I, Curby KM. A perceptual traffic jam on highway N170: Interference between face and car expertise. *Current Directions in Psychological Science*. 2005; 14:30–33.

- Grossman JB, Klin A, Carter AS, Volkmar FR. Verbal bias in recognition of facial emotions in children with Asperger Syndrome. *Journal of Child Psychology and Psychiatry*. 2000; 41(3):369–379. [PubMed: 10784084]
- Hadjikhani N, Joseph RM, Snyder J, Chabris CF, Clark J, Steele S, et al. Activation of the fusiform gyrus when individuals with autism spectrum disorder view faces. *NeuroImage*. 2004; 22:1141–1150. [PubMed: 15219586]
- Happé F. An advanced test of Theory of Mind: Understanding of story characters' thoughts and feelings by able autistic, mentally handicapped and normal children and adults. *Journal of Autism and Developmental Disorders*. 1994; 24:129–134. [PubMed: 8040158]
- Happé F. Autism: Cognitive deficit or cognitive style? *Trends in Cognitive Sciences*. 1999; 3:216–222. [PubMed: 10354574]
- Henderson HA, Schwartz CB, Mundy P, Burnette C, Sutton SK, Zahka N, Pradella A. Response monitoring, the error-related negativity, and differences in social behavior in autism. *Brain and Cognition*. 2006; 61:96–109. [PubMed: 16458401]
- Hobson P, Ouston J, Lee A. What's in a face? The case of autism. *British Journal of Psychology*. 1988; 79:441–453. [PubMed: 3208000]
- Itier RJ, Taylor MJ. Inversion and contrast polarity reversal affect both encoding and recognition processes of unfamiliar faces: A repetition study using ERPs. *NeuroImage*. 2002; 15:353–372. [PubMed: 11798271]
- Itier RJ, Taylor MJ. Effects of repetition and configural changes on the development of face recognition processes. *Developmental Science*. 2004a; 7:469–487. [PubMed: 15484595]
- Itier RJ, Taylor MJ. Effect of repetition learning on upright, inverted, contrast-reversed face processing using ERPs. *NeuroImage*. 2004b; 21:1518–1532. [PubMed: 15050576]
- Itier RJ, Taylor MJ. Face recognition memory and configural processing: A developmental ERP study using upright, inverted, and contrast-reversed faces. *Journal of Cognitive Neuroscience*. 2004c; 16:487–502. [PubMed: 15072683]
- Itier RJ, Taylor MJ. N170 or N1? Spatiotemporal differences between object and face processing using ERPs. *Cerebral Cortex*. 2004d; 14:132–142. [PubMed: 14704210]
- Izard C, Fine S, Schultz D, Mostow A, Ackerman B, Youngstrom E. Emotion knowledge as a predictor of social behavior and academic competence in children at risk. *Psychological Science*. 2001; 12:18–23. [PubMed: 11294223]
- Jansson-Verkasalo E, Ceponiene R, Kielinen M, Suominen K, Jantti V, Linna S, et al. Deficient auditory processing in children with Asperger Syndrome, as indexed by event-related potentials. *Neuroscience Letters*. 2003; 338:197–200. [PubMed: 12581830]
- Jansson-Verkasalo E, Kujala T, Jussila K, Mattila ML, Moilanen I, Naatanen R, et al. Similarities in the phenotype of the auditory neural substrate in children with Asperger syndrome and their parents. *European Journal of Neuroscience*. 2005; 22:986–990. [PubMed: 16115221]
- Jemel B, Mottron L, Dawson M. Impaired face processing in autism: Fact or artifact? *Journal of Autism and Developmental Disorders*. 2006; 36(1):91–106. [PubMed: 16477517]
- Jeste SS, Nelson CA. Event related potentials in the understanding of autism spectrum disorders: An analytical review. *Journal of Autism and Developmental Disorders*. 2009; 39:495–510. [PubMed: 18850262]
- Just MA, Cherkassky VL, Keller TA, Kana RK, Minshew NJ. Functional and anatomical cortical underconnectivity in autism: Evidence from an fMRI study of an executive function task and corpus callosum morphometry. *Cerebral Cortex*. 2007; 17:951–961. [PubMed: 16772313]
- Lord, C.; Rutter, M.; Dilavore, P.; Risi, S. *Manual: Autism Diagnostic Observation Schedule*. Los Angeles, CA: Western Psychological Services; 1999.
- Magnun G. Neural mechanisms of visual selective attention. *Psychophysiology*. 1995; 32:4–18. [PubMed: 7878167]
- McPartland J, Dawson G, Webb SJ, Panagiotides H, Carver LJ. Event related brain potentials reveal anomalies in temporal processing of faces in autism spectrum disorder. *Journal of Child Psychology and Psychiatry*. 2004; 45:1235–1245. [PubMed: 15335344]
- O'Connor K, Hamm JP, Kirk IJ. The neuropsychological correlates of face processing in adults and children with Asperger's Syndrome. *Brain and Cognition*. 2005; 59:82–95. [PubMed: 16009478]

- O'Connor K, Hamm JP, Kirk IJ. Neurophysiological responses to face, facial regions and objects in adults with Asperger's syndrome: An ERP investigation. *International Journal of Psychophysiology*. 2007; 63:283–293. [PubMed: 17267061]
- Passarotti A, Paul B, Stiles J. Development affects the ventral and dorsal processing streams differently: An fMRI study on face and location processing in children, teenagers, and adults. *NeuroImage*. 2001; 13:S345.
- Pierce K, Haist F, Sedaghat F, Courchesne E. The brain response to personally familiar faces in autism: Findings of fusiform activity and beyond. *Brain: A Journal of Neurology*. 2004; 127(12): 2703–2716. [PubMed: 15319275]
- Rossion B, Curran T, Gauthier I. A defense of the subordinate-level expertise account for the N170 component. *Cognition*. 2002; 85:189–196. [PubMed: 12127699]
- Rossion B, Delvenne JF, Debatisse D, Goffaux V, Bruyer R, Crommelinck M, et al. Spatio-temporal localization of the face inversion effect: An event related potentials study. *Biological Psychology*. 1999; 50:173–189. [PubMed: 10461804]
- Stormark KM, Braarud HC. Infants' sensitivity to social contingency: A "double video" study of face-to-face communication between 2- and 4-month-olds and their mothers. *Infant Behavior and Development*. 2004; 27:195–203.
- Tanaka JW, Curran T. A neural basis for expert object recognition. *Psychological Science*. 2001; 12:43–47. [PubMed: 11294227]
- Taylor MJ. Non-spatial attentional effects on P1. *Clinical Neurophysiology*. 2002; 113:1903–1908. [PubMed: 12464327]
- Taylor MJ, Batty M, Itier RJ. The faces of development: A review of early face processing over childhood. *Journal of Cognitive Neuroscience*. 2004; 16:1426–1442. [PubMed: 15509388]
- Taylor MJ, Edmonds GE, McCarthy G, Allison T. Eyes first! Eye processing develops before face processing in children. *NeuroReport*. 2001; 12:1671–1676. [PubMed: 11409737]
- Taylor MJ, McCarthy G, Saliba E, Degiovanni E. ERP evidence of developmental changes in processing of faces. *Clinical Neurophysiology*. 1999; 110:910–915. [PubMed: 10400205]
- Tottenham N, Tanaka J, Leon A, McCarry T, Nurse M, Hare T, et al. The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*. 2009; 168:242–249. [PubMed: 19564050]
- Townsend J, Westerfield M, Leaver E, Makeig S, Jung P, Pierce K, et al. Event-related brain response abnormalities in autism: Evidence for impaired cerebello-frontal spatial attention networks. *Cognitive Brain Research*. 2001; 11:127–145. [PubMed: 11240116]
- Williams, P.; Weiss, L.; Rolfhus, E. Wechsler Intelligence Scale for Children – IV, Technical Report 1, Theoretical Model & Test Blueprint. San Antonio, TX: The Psychological Corporation; 2003a.
- Williams, P.; Weiss, L.; Rolfhus, E. Wechsler Intelligence Scale for Children – IV, Technical Report 2, Psychometric Properties. San Antonio, TX: The Psychological Corporation; 2003b.

Upright Faces **Inverted Faces** **Upright Vehicles** **Inverted Vehicles**

Figure 1.
Sample stimuli for each condition.

Figure 2.
Electrode groups over which data were averaged for the P1 component (top) and the N170 component (bottom).

Figure 3.

Grand averaged ERP waveforms to upright faces, upright vehicles, inverted faces, and inverted vehicles for children with autism and typical development, regardless of age, and younger children and older children, regardless of diagnostic group. Electrode 91 is used as the prototypical electrode. All waveforms have a 100 ms pre-stimulus and a 300 ms post-stimulus interval.

Figure 4.
The interaction between stimulus type and age on P1 amplitude.

Figure 5.
The interaction between face orientation and diagnostic group on P1 amplitude.

Figure 6.
The interaction between face orientation and age on N170 amplitude.

Table 1

Participant characteristics

	Autism			Typical Development		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
Age (months)	159.56	33.27	113–209	172.73	24.55	108–203
WISC-IV VCI	97.67	14.30	77–130	104.73	12.79	81–136
WISC-IV PRI	103.07	14.59	69–135	100.50	15.53	67–130
ADOS Social Interaction Score	8.78	2.53	4–14	1.14	1.13	0–3
SCQ Social Interaction Score	8.15	3.49	1–14	1.41	1.33	0–5
Children's Eyes Total	20.05 [*]	2.87 [*]	15–26 [*]	19.91	2.96	13–24
Strange Stories Total	19.45 [*]	2.82 [*]	15–24 [*]	21.90 [*]	1.48 [*]	18–24 [*]

Note:

^{*} *n* = 20

ADOS = Autism Diagnostic Observation Schedule; SCQ = Social Communication Questionnaire; WISC-IV VCI = Wechsler Intelligence Scale for Children-IV Verbal Comprehension Index; PRI = Perceptual Reasoning Index

Table 2

P1 mean amplitude values in μV , evaluated at a mean age of 165.47; P1 mean latency values in ms, evaluated at a mean age of 165.47 months and mean verbal IQ of 100.84

	Autism	Typical Development
Amplitude		
Faces	15.31 (1.23)	17.13 (1.37)
Upright Faces	15.07 (1.27)	16.16 (1.41)
Inverted Faces	15.55 (1.23)	18.10 (1.36)
Vehicles	14.98 (1.20)	16.90 (1.34)
Latency		
Faces	114.98 (1.91)	116.07 (2.13)
Upright Faces	112.75 (2.10)	113.45 (2.33)
Inverted Faces	117.21 (1.98)	118.69 (2.21)
Vehicles	120.28 (2.16)	118.48 (2.40)

Note: Standard deviations are in brackets.

Table 3

N170 mean amplitude values in μV , evaluated at a mean age of 165.47 months; N170 mean latency values in ms, evaluated at a mean age of 165.47 months

	Autism	Typical Development
Amplitude		
Faces	3.15 (0.77)	4.51 (0.86)
Upright Faces	2.44 (0.77)	3.63 (0.85)
Inverted Faces	3.86 (0.84)	5.40 (0.93)
Vehicles	3.12 (0.75)	3.40 (0.83)
Latency		
Faces	181.95 (3.62)	172.78 (4.02)
Upright Faces	176.22 (3.74)	166.05 (4.15)
Inverted Faces	187.69 (4.20)	179.52 (4.67)
Vehicles	204.88 (3.20)	192.14 (3.56)

Note: Standard deviations are in brackets.

Table 4

Partial Correlations between ERP Measures for Upright Faces and Atypical Social Behavior and Social Cognition Scores, Controlling for Age and Verbal IQ

	Atypical Social Behavior Score	Social Cognition Score
Autism		
P1 Amplitude	0.27	0.01
P1 Latency	0.31	-0.11
N170 Amplitude	0.03	0.18
N170 Latency	-0.26	-0.31
Typical Development		
P1 Amplitude	0.68**	-0.50*
P1 Latency	0.04	-0.08
N170 Amplitude	0.56*	0.01
N170 Latency	-0.01	-0.22

Note:

*
 $p < 0.05$,

**
 $p < 0.01$

ERP = event-related potential