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Consonant differentiation mediates the discrepancy between non-verbal and verbal abilities in children with ASD

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Abstract

Background Many children with autism spectrum disorder (ASD) demonstrate verbal communication disorders reflected in lower verbal than non-verbal abilities. The present study examined the extent to which this discrepancy is associated with atypical speech sound differentiation.
Methods Differences in the amplitude of auditory event-related potentials elicited by contrasting consonant–vowel syllables during a passive listening paradigm were used to assess speech sound differentiation in 24 children with ASD and 18 chronological age-matched children with typical development (TD), *M* age 6.90 years ($SD = 1.39$).
Results Results revealed that compared with TD peers, children with ASD showed reduced consonant differentiation in the 84- to 308-ms period. Brain responses indexing consonant differentiation were negatively related to the degree of discrepancy in non-verbal and verbal abilities and mediated the relationship between diagnostic group membership and the greater discrepancy.
Conclusions We discuss the theoretical and clinical implications of the brain's response to speech sound contrasts possibly explaining the greater non-verbal versus language ability in children with ASD compared with that in typically developing children.

Keywords autism, consonant differentiation, ERP, language, speech perception

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Autism spectrum disorder (ASD) includes symptoms in the areas of social and communicative domains as well as repetitive behaviours [Diagnostic and Statistical Manual of Mental Disorders Fifth Edition (DSM 5); APA 2013]. Many children with ASD evidence receptive and expressive language abilities that are below their non-verbal cognitive abilities (Loucas *et al*. 2008; Kwok *et al*. 2015) and may demonstrate deficits similar to those of individuals with specific language impairment (Tager-Flusberg 2006; Herbert & Kenet 2007). This type of a verbal communication disorder is particularly interesting because overall intellectual disability (ID) is unlikely to explain it (Stark & Tallal 1981).

Although some form of language deficits has been reported in up to 60% of children with ASD (Kjelgaard & Tager-Flusberg 2001), the estimates of the proportion of children with ASD who demonstrate higher non-verbal than verbal ability vary. Some have reported such discrepancy to be common but not universal (Lincoln *et al.* 2007). Others noted this profile to be present more often in younger (e.g. preschool) and lower-functioning (IQ < 80) children with ASD, with the extent of the discrepancy decreasing with age (Joseph *et al.* 2002; Mayes & Calhoun 2003), mainly because of higher scores in the verbal domain for older children (Mayes & Calhoun 2003). Tager-Flusberg & Joseph (2003) observed higher non-verbal than verbal abilities measured by Differential Ability Scales in 34% (14/47) of children with ASD (6–13 years), while 48% (35/73) of preschoolers with ASD showed a similar discrepancy (Joseph *et al.* 2002). Understanding the mechanisms underlying language deficits not due to ID will allow for the development of novel treatment targets as well as diagnostic tools for better identification of early signs of communication delays.

Individual differences in the extent of language deficits relative to non-verbal ability are thought to have multiple origins. Difficulties in auditory information processing offer one possible explanation. Previous studies in children with specific language impairment in the absence of ASD noted the importance of effective speech sound processing for proper language development (e.g. Benasich *et al.* 2002). They also reported deficits in basic auditory perception processes at the level of individual consonants or vowels (McArthur & Bishop 2005; Shafer *et al.* 2005).

Event-related potentials (ERPs), which measure brain activity following presentation of a stimulus, have been widely used to examine auditory processing in children and adults. ERPs provide high temporal resolution that allows for the quantification of neural processing with great precision. Additionally, many ERP paradigms do not require active engagement from the participant, making this methodology especially valuable for use in populations who may be unable or unmotivated to provide reliable behavioural responses (Yoder *et al.* 2006), and suitable for use across multiple ages, including infants. Identifying the connection between neural evidence of atypical speech sound processing and language deficits could facilitate management of risk for poor developmental outcomes by providing objective evidence of altered responses to speech prior to the emergence of behavioural symptoms.

The majority of ERP studies examining auditory processing in individuals with ASD had used non-speech tones (refer to Haesen *et al.* 2011 and Hitoglou *et al.* 2010 for reviews). However, speech sound stimuli could be more relevant to understanding possible sources of language deficits, because speech sounds are more complex than tones, and their processing relies on brain mechanisms overlapping with, but not identical to, those engaged by non-speech stimuli (Dehaene-Lambertz *et al.* 2005).

The existing auditory ERP studies in typical and atypical populations can be broadly categorised into those assessing speech sound processing and those measuring differentiation of contrasting speech stimuli. Speech processing studies may include a single stimulus or multiple stimuli of interest and focus on ERP characteristics (e.g. amplitude or latency of a peak) associated with the individual sounds. In children with ASD, speech processing studies reported reduced amplitudes of P1/N1 responses following passive exposure to a single syllable (Russo *et al.* 2009) or showed atypical hemisphere lateralisation of N1 latency and amplitude favouring the right hemisphere during an active syllable detection task (Dawson *et al.* 1989), suggesting altered sensory processes.

In contrast, speech sound differentiation studies use at least two stimuli that differ on one critical dimension (e.g. voice onset timing or place of articulation) and examine the difference in ERPs as the metric of stimulus differentiation. Prior speech differentiation studies in children with ASD included mainly vowels and produced varied findings, suggesting intact or enhanced (Kemner *et al.* 1995; Lepistö *et al.* 2005; Lepistö *et al.* 2008; Whitehouse & Bishop 2008), reduced (Čeponienė *et al.* 2003), or delayed (Oram Cardy *et al.* 2005) stimulus differentiation, as well as atypical right hemisphere lateralisation of brain responses (Flagg *et al.* 2005; Lepisto *et al.* 2006). This variability in results could not be attributed to task demands, as the majority of the studies involved passive listening. Fewer studies in ASD have examined differentiation of consonant–vowel (CV) syllables, which are building blocks of English words. In two published reports, differences in ERPs elicited by the contrasting consonants were delayed (Jansson-Verkasalo *et al.* 2003) or reduced/absent (Kuhl *et al.* 2005).

Many of these studies employed an oddball stimulus presentation paradigm and its accompanying mismatch negativity (MMN) response, but this approach arguably has several limitations (refer to Kujala *et al.* 2007 for a review). In particular, the MMN response is not always detectable, even when behavioural responses evidence stimulus discrimination (e.g. Wunderlich & Cone-Wesson 2001; Sharma *et al.* 2006). This could be because of masking by overlapping N1 or P3 responses (Näätänen *et al.* 2005; Duncan *et al.* 2009). Recently, Kujala *et al.* (2010) included consonant contrasts in a multi-feature MMN paradigm but observed no MMN responses in either the ASD or typical group (age 8–12 years); thus, no conclusions about consonant differentiation could be made. The likelihood of an absent MMN responses increases with decreasing age (Leppänen *et al.* 1997; Cheour *et al.* 1998). Moreover, in young school-age children, the MMN response demonstrated poor test–retest reliability (Uwer & von Suchodoletz 2000; Räikkönen *et al.* 2003), reducing its value for investigating neural mechanisms underlying verbal skills in young children with ASD.

The present study was designed to expand prior findings regarding speech sound processing in children with ASD in several ways: (1) by including a more diverse set of CV syllables; (2) by employing equiprobable stimulus presentation that has been previously used to study speech sound differentiation in children with and without developmental disabilities (Molfese & Molfese 1997; Espy *et al.* 2004; Yoder *et al.* 2006; Key *et al.* 2009; McArthur *et al.* 2010); and (3) by explicitly testing whether speech–sound differentiation ability (difference in ERPs to contrasting stimuli) could explain the difference in the extent of non-verbal versus verbal ability discrepancy in children with ASD compared with chronological age-matched children with TD.

We expected syllable differentiation to be reflected in amplitude differences of early auditory ERP responses (P1-N1-P2), known to be sensitive to stimulus physical characteristics and perceptual categorisation. We hypothesised that children with ASD would process CV syllables atypically, resulting in reduced differences in ERP responses to contrasting speech stimuli, which could in turn contribute to greater non-verbal and verbal discrepancies in children with ASD than typical peers. The comparison group matched on chronological age and non-verbal ability allowed us to focus on between-group differences in language deficits by controlling for factors related to maturation, perceptual experience and intellectual ability, which may affect ERP responses to speech sounds.

Method

Participants

Forty-two children (35 male subjects, 7 female subjects) participated in the study. Eighteen children (4 female subjects), *M* age 7.14 years ($SD = 1.45$), were typically developing (TD) with no reported family history of ASD. Twenty-four children (3 female subjects), *M* age 6.71 years ($SD = 1.34$), had a diagnosis of ASD based on the DSM-IV definition (14 – autism, 3 – Asperger syndrome, 7 – pervasive developmental disorder – not otherwise specified). Diagnoses were made by licensed psychologists, and 16/24 (67%) children were diagnosed at a university-based autism clinic using the Autism Diagnostic Observation Schedule (ADOS) either alone or in combination with the Autism Diagnostic Interview – Revised (ADI-R) to support the clinical diagnosis. Of the remaining children, four (17%) were diagnosed by community professionals, and two (8%) by their school systems. Parents of two participants (8%) did not provide the information about the source of the diagnosis. The participants with ASD were required to have sufficient language skills and intellectual ability to understand and follow simple instructions associated with the study protocol.

The participant groups did not differ significantly in age ($P = 0.326$, $d = 0.308$) or non-verbal ability ($P = 0.178$, $d = 0.433$; refer to Table 1 for a summary of participant characteristics). However, the TD group had higher verbal abilities and higher overall cognitive abilities, as measured by Kaufman Brief Intelligence Test-2 (K-BIT2; Kaufman & Kaufman 2004). Three children in each group were left-handed, the rest were right-handed, as determined by the Edinburgh Handedness Inventory (Oldfield 1971), $M_{ASD} = 0.66$, $SD = 0.49$, $M_{TD} = 0.72$, $SD = 0.39$. All children were reported by parents to have normal hearing and vision.

Four additional children with ASD were excluded from the study because of the lack of cooperation with the electrode placement. Data from one TD child

Table 1 Participant sample characteristics: Means (SD) and ranges

	ASD		TD		*p*-value
N (m/f)	24 (21/3)		18 (15/3)		
Age (years)	6. 71 (1.34)	5.08–9.92	7.14 (1.45)	5–10.17	0.326
Handedness	0.66 (0.49)	−0.77–1	0.72 (0.39)	−0.07–1	0.643
K-BIT2 IQ	93.88 (17.41)	60–135	110.44 (13.05)	88–136	0.001
Verbal	90.46 (17.48)	49–124	111.61 (12.29)	82–127	<0.001
Non-verbal	98.54 (18.10)	61–138	105.78 (15.17)	80–138	0.178
Non-verbal vs. verbal discrepancy	8.08 (18.95)	−24–57	−5.83 (15.80)	−45–19	0.016
% Significant non-verbal > verbal*	29 (7/24)		11 (2/18)		

*Discrepancy of 15 points or more.

were excluded because of an insufficient number of artifact-free trials. The research was prospectively reviewed and approved by the university ethics committee. Parents provided written informed consent, and children provided their assent prior to completing the study procedures.

Procedure

All data were collected during a single visit. The behavioural testing preceded the ERP recording.

Behavioural testing

Kaufman Brief Intelligence Test-2 (K-BIT2) is a brief assessment of verbal and non-verbal abilities in persons 4–90 years of age. K-BIT2 provides verbal and non-verbal standard scores and an overall composite IQ score, each with a mean of 100 and a standard deviation of 15. The scores have high internal consistency (for children 4–18 years, mean = 0.88–0.90). K-BIT2 is widely used in research settings and is suitable for typical individuals and those with intellectual and developmental disabilities, including ASD (Klinger *et al.* 2009). It was administered individually by a trained research assistant and lasted approximately 15 min.

Event-related potential acquisition

ERP data were acquired individually in a sound-attenuated room using a 128-channel Geodesic Sensor Net with Ag/AgCl electrodes (EGI, Inc., Eugene, OR) connected to high-impedance amplifiers. Data were sampled at 250 Hz with the filters set to 0.1–30 Hz and electrode impedance levels below 40 kΩ. All electrodes were referred to vertex during recording and re-referenced offline to an average reference.

Event-related potential stimuli

The stimuli included six CV syllables /ba/, /da/, /ga/, /bu/, /du/, and /gu/, originally employed by Stevens & Blumstein (1978) and accurately identified by the adult subjects in that study as members of their respective phonetic categories. A single five-formant token for each CV was synthesised on a Klatt (cascade) synthesiser, so that the amplitude of individual formants was modulated as a function of the respective formant frequencies, as in natural speech. The central frequencies of the steady-state portion of the formants were kept constant across the consonants and only varied as a function of the vowel sounds. Duration of F1 transition ranged between 15 and 45 ms across tokens depending on the initial consonant and the following vowel. Transition duration for all the other formants was 40 ms. Consonants were followed by a 250 ms steady state vowel. Rise and decay times were equivalent across sounds.

Event-related potential paradigm

To reduce possible confounds related to motivation and attention, to facilitate comparisons with prior results obtained using passive listening paradigms, and based on recent findings suggesting that greater group differences in auditory processing between typical individuals and those with ASD may be observed in passive tasks (Dunn *et al.* 2007;

Whitehouse & Bishop 2008), the participants were instructed to sit quietly and listen to the speech sounds, but no active stimulus identification or behavioural responses were required. The syllables were presented at 75 dB SPL(A) as measured at the ear level, through a speaker positioned approximately 100 cm above the midline of the child's head. All speech sounds were presented in random order, 25 times each, for a total of 150 trials over the course of 10 min. Interstimulus intervals varied randomly between 1.6–2.6 s to prevent habituation to stimulus onset.

Recording of the brainwaves was controlled by Net Station software (v.4.3; EGI, Inc., Eugene, OR). E-Prime (v.1.2; PST, Inc., Pittsburgh, PA) controlled stimulus presentation. A researcher present in the testing room continuously monitored child's behaviour and electroencephalogram (EEG). If artefacts contaminated the EEG for two consecutive trials, stimulus presentation could be manually suspended until the source of noise was addressed, and resumed when the EEG signal was optimal.

Data analysis

The EEG was segmented on stimulus onset to include a 100-ms prestimulus baseline and a 700-ms post-stimulus interval. Trials contaminated by ocular and movement artefacts were rejected from further analysis using an automated screening algorithm in NetStation followed by a manual review. Data from electrodes with poor signal quality were reconstructed using spherical spline interpolation (Srinivasan *et al.* 1998). If more than 15 electrodes (12% of the array) within a trial had poor signal, the entire trial was discarded. To be included in the statistical analyses, each participant had to have a minimum of 10 artefact-free trials per stimulus condition. Although on average slightly more trials were retained for children with ASD than with TD, $M_{ASD} = 15.72$, $SD = 3.72$; $M_{TD} = 13.73$, $SD = 2.33$, these group differences only approached significance ($P = .053$). There were no significant correlations between the number of trials retained and age, IQ, or non-verbal-verbal IQ discrepancy for the combined sample or for either of the participant groups.

Artefact-free ERPs were averaged and baseline-corrected by subtracting the average microvolt value across the 100-ms prestimulus interval from the post-stimulus segment. To reduce the number of potential significance tests (6 sounds × 128 electrodes × 175 time samples = 134 400 data points per participant), a spatial principal components analysis (PCA) using a covariance matrix and Promax rotation was performed to group data from 128 electrodes into a small set of 'virtual electrodes', each representing a spatially contiguous group of electrodes with similar ERP waveforms (Spencer *et al.* 1999). Specific electrodes comprising each cluster were identified using the criterion of factor loadings of $|0.6|$ or greater. Data for individual electrodes within each cluster were averaged. Next, clustered data were submitted to a temporal PCA (tPCA) with Varimax rotation. This process reduced 175 time samples (700 ms) to a small set of non-correlated components corresponding to the temporal windows of maximal variability in the waveforms, such as slopes or peaks. The number of tPCA factors was determined using the scree test (Cattell 1966), and temporal windows were labelled based on consecutive time samples with factor loadings of $|0.6|$ or greater.

To further limit the number of variables in the statistical analyses, only data for the anterior and posterior temporal scalp regions (overlapping T3/T4 and T5/T6 locations previously used in ERP studies of speech sound processing; Fig. 1) were used as dependent variables. The repeated-measures ANOVA examined speech sound differentiation using a 4-factor design of Consonant (3: b, d, g) × Vowel (2: a, u) × Electrode (2: anterior temporal, posterior temporal) × Hemisphere (2: left, right), with Huynh–Feldt correction. Significant interactions involving Consonant or Vowel factors were further examined using pair-wise *t*-tests. The false discovery rate (FDR) approach (Benjamini & Hochberg 1995) was used to control for multiple significance tests in the follow-up analyses. This approach was selected over the Bonferroni correction (Hochberg 1988) because the former is more statistically powerful and fits the inter-correlational nature of ERP data better than the latter (Crowley *et al.* 2012).

To constrain the number of significance tests even further, ERPs of the TD sample were analysed first to identify the particular temporal intervals and speech sound contrasts where typical children demonstrated statistically significant speech sound differentiation. We then tested the hypotheses of atypical speech

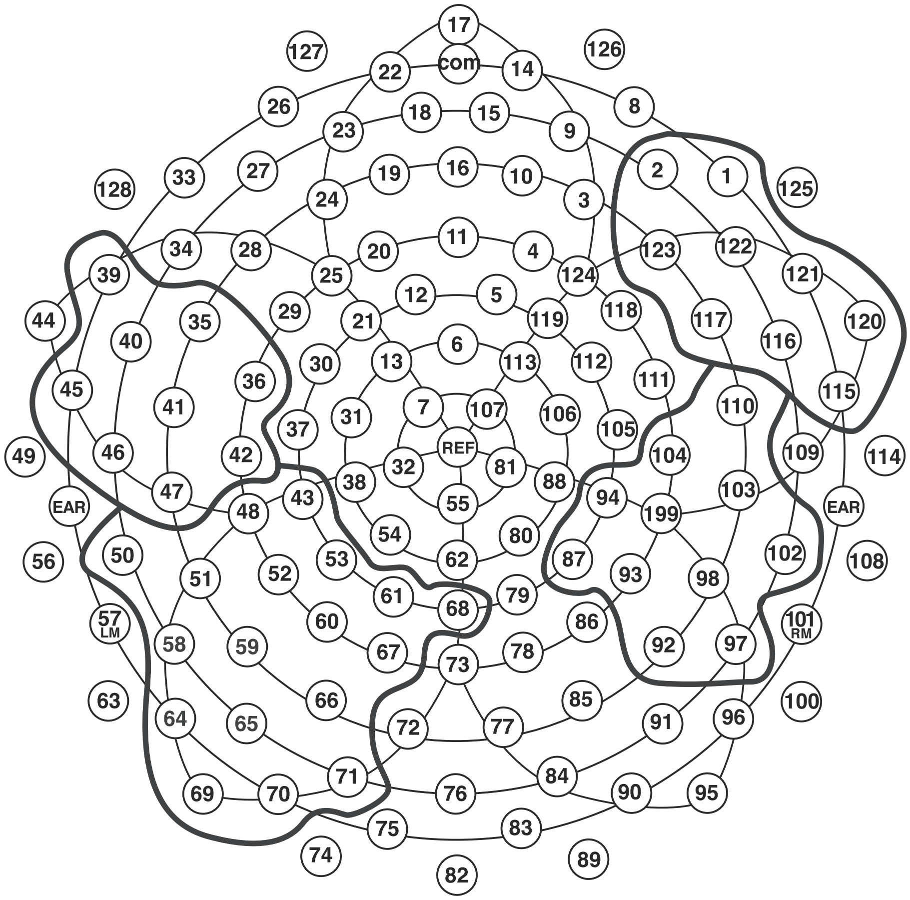

Figure 1 128-cannel electrode layout and the electrode clusters used in the analyses.

sound differentiation in children with ASD by examining the presence of stimulus-related differences only in that subset of ERPs presumably reflecting typical speech sound processing. Between-stimuli differences in factor scores were the dependent measures in one-way ANOVAs with Group (ASD versus TD) as the between-subject factor.

To examine whether speech sound differentiation reflected in ERP response differences is related to non-verbal and verbal skill discrepancies, Pearson correlations were tested between ERP variables showing significant stimulus differentiation and the difference score between non-verbal and verbal standard scores on the K-BIT2. Finally, a mediation analysis (Tofighi & MacKinnon 2011) was conducted to test the hypothesis that ERP measures that show significant group differences in speech sound differentiation mediate the relationship between the diagnostic group status (TD versus ASD) and non-verbal and verbal skill discrepancies. Because typical children were expected to show greater ERP differentiation of speech sounds and reduced non-verbal and verbal ability discrepancies, a one-tailed test was used to judge the significance of the indirect path in the mediation analysis.

Results

The temporal PCA applied to the entire data set identified five temporal windows accounting for 83.97% of the total variance in ERPs: 0–76 ms (Factor 5, 8.67%), 84–196 ms (Factor 4, 13.78%), 196–308 ms (Factor 2, 14.37%), 320–444 ms (Factor 3, 14.00%) and 432–700 ms (Factor 1, 33.16%).

Typical speech sound processing

Within the TD group, the repeated-measures ANOVA identified consonant and/or vowel related differences in ERPs for four of the five temporal windows (excluding Factor 5 because it was too early for speech differentiation to affect). Of the remaining factors, the earliest interval, 84–196 ms, was characterised by a main effect of Consonant, $F_{2,24} = 5.135$, $P = 0.011$, partial $\eta^2 = 0.232$, and interactions of Consonant × Vowel × Hemisphere, $F_{2,34} = 6.296$, $P = 0.005$, partial $\eta^2 = 0.270$, and Consonant × Vowel × Electrode × Hemisphere, $F_{2,34} = 4.328$, $P = .021$, partial $\eta^2 = .203$. Follow-up analyses revealed a number of significant speech sound contrasts, but only the consonant difference associated with the main effect remained significant following the FDR procedure: overall, /g/-initial syllables elicited more positive responses than /b/-initial syllables, $t(17) = 3.238$, $P = 0.005$, $d = 0.763$ (Fig. 2).

In the 196- to 308-ms interval, there was a Consonant × Electrode interaction, $F_{2,34} = 5.114$, $P = 0.013$, partial $\eta^2 = 0.231$, where /b/-syllables elicited more positive amplitudes than /d/-syllables, $t(17) = 3.650$, $P = 0.002$, $d = 0.860$, over the anterior temporal sites. There were no significant differences at the posterior electrodes, *p*'s = 0.072–0.642.

The 320- to 444-ms interval was characterised by a Vowel × Electrode interaction, $F_{1,17} = 7.472$, $P = 0.014$, partial $\eta^2 = 0.305$. Follow-up analyses indicated that /a/-ending sounds elicited more positive amplitudes than /u/-ending stimuli at the anterior temporal sites, $t(17) = 2.632$, $P = 0.017$, $d = 0.62$. As is common in ERP studies (Woldorff *et al.* 1998; Korzyukov *et al.* 2003), the direction of these differences was reversed at the posterior temporal sites, $t(17) = 2.193$, $P = 0.042$, $d = 0.52$.

In the final interval of 432–700 ms, there was a Consonant × Electrode interaction, $F_{2,34} = 4.439$, $P = 0.019$, partial $\eta^2 = 0.207$, because of the /b/-syllables eliciting more positive waveforms than /g/-syllables at posterior temporal locations, $t(17) = 3.074$, $P = 0.007$, $d = 0.725$. There was also a Consonant × Vowel × Hemisphere interactions, $F_{2,34} = 5.510$, $P = 0.010$, partial $\eta^2 = 0.245$, but the follow-up analyses were not significant after the FDR correction.

In summary, stimuli differentiation was observed in the TD sample at 84–196 and 432–700 ms between /g/

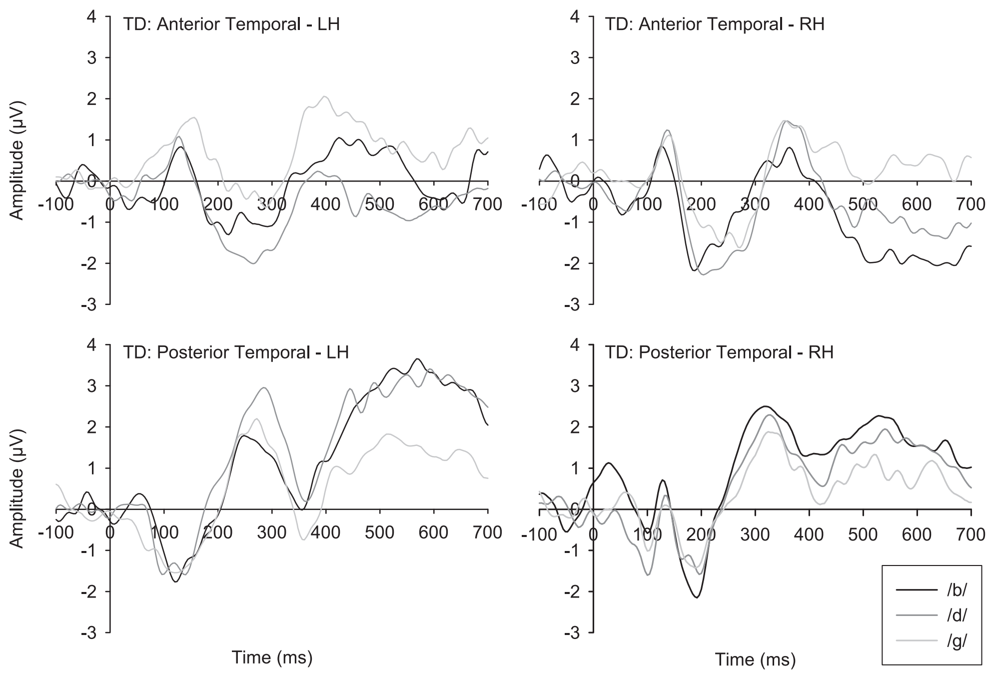

Figure 2 Average ERP waveforms in response to consonant contrasts at anterior and posterior temporal locations in typical children.

and /b/, at 196–308 ms between /b/ and /d/ and at 320–444 ms between /a/ and /u/.

Between-group differences in speech sound differentiation

Group differences between children with ASD and TD were observed for the /g/-/b/ contrast in 84- to 196-ms interval, $F_{1,40} = 6.994$, $P = 0.012$, $d = 0.848$, and for the /b/-/d/ contrast at the anterior temporal locations within 196–308 ms, $F_{1,40} = 3.976$, $P = 0.053$, $d = 0.623$ (Fig. 3). In both cases, larger differences in ERPs elicited by the contrasting speech sounds were observed in the TD than ASD group. The /a/-/u/ difference in the 320- to 444-ms interval and the /g/-/b/ difference in 432- to 700-ms interval that were identified in the TD group did not yield significant between-group differences (p's = 0.063–0.094).

Between-group differences in the discrepancy between non-verbal and verbal scores

The participant groups were statistically different in the extent of the non-verbal and verbal discrepancies, $F_{1,40} = 6.371$, $P = 0.016$, $d = 0.797$, with lower mean discrepancy values in children with TD than ASD.

For 5- to 10- year-old children, a discrepancy of 15 points or greater between verbal and non-verbal standard scores on the K-BIT2 is considered to be a noteworthy difference (Kaufman & Kaufman 2004). In the group of children with ASD, 29% (7/24) demonstrated such discrepancy favouring non-verbal performance, while 8% (2/24) had notably higher verbal than non-verbal scores. In the TD group, 11% (2/18) demonstrated the discrepancy toward higher non-verbal performance, and 28% (5/18) scored higher in the verbal than non-verbal domain.

Brain-behaviour correlations

For the combined sample (TD and ASD), the size of the /b/-/d/ difference at the anterior temporal locations within 196–308 ms was negatively correlated with the extent of discrepancy in K-BIT2 non-verbal versus verbal standard scores, $r = -0.399$, $P = 0.009$. This means that greater differences in ERP responses to speech sounds were associated with lower non-verbal vs. verbal difference scores. The extent of discrepancy did not correlate with the overall IQ in the combined sample or in either of the groups (p's = 0.383–0.852).

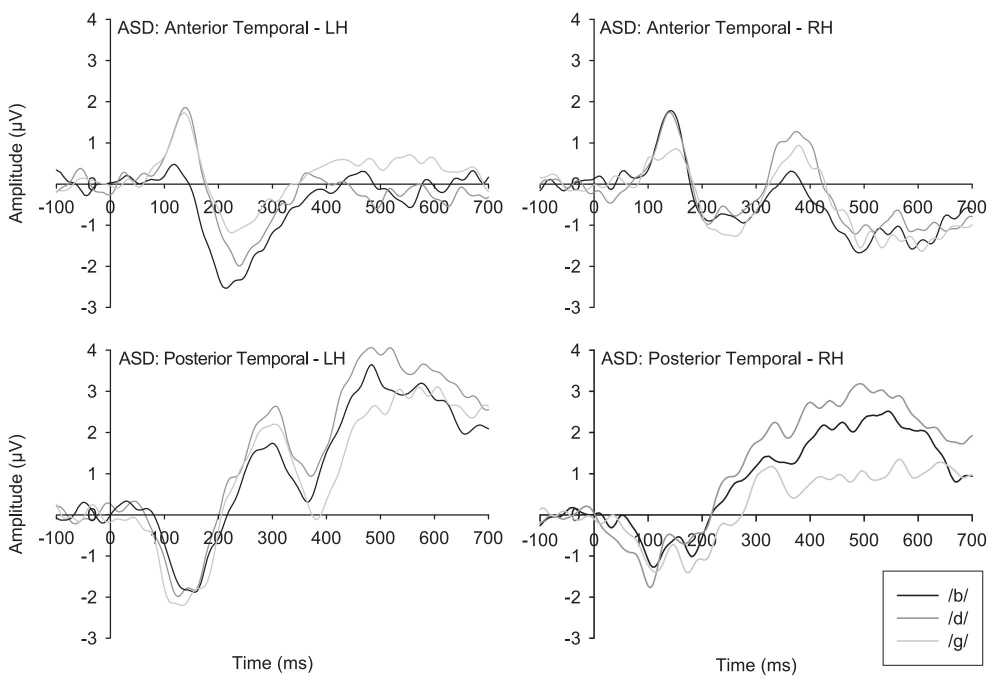

Figure 3 Average ERP waveforms in response to consonant contrasts at anterior and posterior temporal locations in children with ASD.

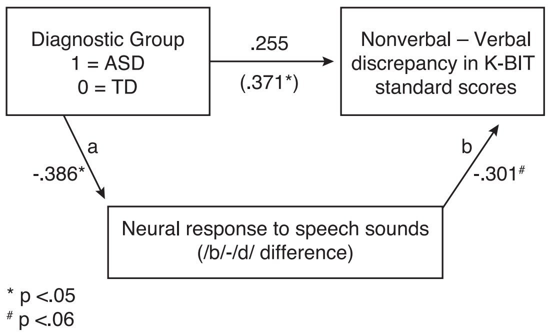

Figure 4 The putative mediated relation between diagnostic group membership and language impairment (non-verbal and verbal standard score discrepancies) through brain response to /b/-/d/ contrast. The standardised coefficient in parentheses is the effect of diagnostic group on K-BIT2 score discrepancy when brain measures are not included in the model.

Mediation analysis

As demonstrated in Fig. 4, difference in ERP responses for the /b/-/d/ contrast at the anterior temporal site during the 196–308 ms window mediated the relationship between diagnostic group membership and non-verbal and verbal score discrepancies. The 90% confidence interval (the appropriate interval for a one-tailed test) for the product of the 'a' and 'b' paths (i.e. the parameter for the indirect relation) did not include zero (0.400–9.675). R-square change values for paths a and b were 0.15 and 0.08, respectively.

Discussion

The purpose of this study was to examine whether, as a group, children with ASD process CV speech stimuli in an atypical way and whether the brain's ability to differentiate speech sounds relates to individual differences in language deficits, quantified as the degree of discrepancy in non-verbal and verbal abilities, and mediates the relationship between diagnostic group membership and such discrepancy. Our results indicated that children with ASD evidence smaller than typical differences in ERP responses to consonant contrasts within 84–308 ms after stimulus onset, and the extent of speech sound differentiation is related to individual differences in non-verbal versus verbal abilities.

We implemented a normative analytic approach, where ERPs of typical children were analysed first to establish the pattern of presumed typical speech sound processing in the brain, which then guided subsequent analyses. Consonant differences were detected within 84–196 ms (/b/-/g/), 196–308 ms (/b/-/d/) and 432–700 ms (/b/-/g/) periods, while vowel differentiation (/a/-/u/) was observed in 320- to 444-ms interval. Next, the differences in brain responses elicited by these sound contrasts were compared between the two diagnostic groups. Children with ASD evidenced reduced consonant differentiation in the 84–196 and 196–308 ms temporal windows, while no group differences reached significance for the remaining two intervals.

The pattern of diagnostic group differences in ERP responses is consistent with the previous studies reporting reduced consonant differentiation in children with ASD (Kuhl *et al.* 2005) but no group differences in vowel differentiation between children with ASD and TD (e.g. Kemner *et al.* 1995; Lepisto *et al.*, 2005). This consistency in results obtained using different speech stimuli and ERP procedures is especially important because it demonstrates that reported findings are unlikely the result of multiple significance testing and that using CV syllables in an equiprobable design is a construct valid way to evaluate speech sound processing in children with ASD. The passive nature of the equiprobable paradigm coupled with its relatively short duration makes it appealing for future use in younger children and in infants at risk for ASD or other communication disorders.

The presence of significant correlations between ERP differences for the contrasting speech sounds and behavioural evidence of non-verbal and verbal discrepancies supports the premise that language deficits that are not explained by cognitive abilities might be explained by individual differences in the brain's ability to differentiate speech stimuli. Incidentally, the 29% rate of K-BIT2 score discrepancy toward higher non-verbal than verbal skills in 5- to 10-year-old children with ASD in the present study was very similar to the 34% rate previously reported for 6- to 13-year-olds with ASD using Differential Ability Scales, a more comprehensive measure of cognitive ability (Joseph *et al.* 2002; Tager-Flusberg & Joseph 2003). This replication of the prevalence rates in a different sample with a different assessment tool confirms that a noteworthy minority of children with ASD have verbal communication disorder in the absence of ID.

An exploratory mediation analysis further indicated that the brain's ability to respond differently to contrasting speech sounds mediates the relationship between the diagnostic group status and non-verbal vs. verbal discrepancies. This finding is new to the literature. While the design does not allow confident causal inferences, the significant indirect effect provides correlational support for the hypothesis that atypical speech sound differentiation in the brain explains, at least in part, greater instances of a substantial non-verbal and verbal ability discrepancy in children with ASD versus TD. The reported association between the neural evidence of diminished consonant discrimination and the non-verbal and verbal skill discrepancies in children with ASD opens a new direction for the development of novel treatment targets as well as early screening tools that could be used in young children or even infants to manage risk for poor communicative outcomes.

While this study yielded novel findings, it has a number of limitations. Although not unusual in size for an ERP study, the typical participant sample was relatively small for the purpose of a true normative analysis, creating the possibility that brain responses of the TD group were not entirely representative of speech sound processing in the general population. Additionally, while the differences in non-verbal functioning between children with TD and ASD were not statistically significant, some might consider them noteworthy. The TD sample could be representing a higher ability subgroup of the general population, as frequently happens in university-based samples of convenience. Yet, the average non-verbal K-BIT2 scores for both groups were very close to the mean, and the standardised between-group mean difference of 0.43 corresponds to a small-to-medium effect size, suggesting that the two groups were comparable.

Our sample of children with ASD was very heterogeneous, representing a spectrum of possible phenotypes. Compared with a more diagnostically or severity-level restricted sample, this high variability may have inflated the correlation between speech differentiation measured by ERPs and language deficits reflected by the non-verbal and verbal standard score discrepancies. Future studies with larger representative samples are needed to determine the external validity of the current findings. Related to the issue of the sample composition is the concern regarding diagnosis. While the majority of the participants in the present sample were diagnosed using ADOS/ADI-R, the instruments used to diagnose some children were unknown and thus may have not been assessed using these gold-standard tools, thereby contributing to increased variability within the ASD group. Finally, all intact group comparison and correlational results are subject to explanation by unmeasured third variables. The K-BIT2 provides a very basic assessment of children's verbal and non-verbal skills. Although it is considered to be acceptable for use with children with ASD 4 years of age or older (Klinger *et al.* 2009), future studies would need to include a wider range of standardised assessments in order to determine the degree to which discrepancies in verbal and non-verbal abilities are different between diagnostic groups and are related to brain measures of speech sound processing.

In summary, the current study is a step toward providing one explanation for language deficits unrelated to IQ (quantified as non-verbal and verbal skill discrepancies) in children with ASD. Improved understanding of the relationship between the brain's response to speech sound contrasts and non-verbal versus language ability in ASD could lead in the future to the development of new approaches for identifying risks for language deficits at an earlier developmental stage.

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