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Links between social and linguistic processing of speech in preschool children with autism: behavioral and electrophysiological measures

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Abstract

Data on typically developing children suggest a link between social interaction and language learning, a finding of interest both to theories of language and theories of autism. In this study, we examined social and linguistic processing of speech in preschool children with autism spectrum disorder (ASD) and typically developing chronologically matched (TDCA) and mental age matched (TDMA) children. The social measure was an auditory preference test that pitted 'motherese' speech samples against non-speech analogs of the same signals. The linguistic measure was phonetic discrimination assessed with mismatch negativity (MMN), an event-related potential (ERP). As a group, children with ASD differed from controls by: (a) demonstrating a preference for the non-speech analog signals, and (b) failing to show a significant MMN in response to a syllable change. When ASD children were divided into subgroups based on auditory preference, and the ERP data reanalyzed, ASD children who preferred non-speech still failed to show an MMN, whereas ASD children who preferred motherese did not differ from the controls. The data support the hypothesis of an association between social and linguistic processing in children with ASD.

Language disorders are a hallmark of autism. Approximately 25% of all children with autism never develop functional language capabilities (Klinger, Dawson & Renner, 2002). Among verbal children with autism, the onset of speech and other developmental milestones are typically delayed (American Psychiatric Association, 1994).

Despite the universality of language impairments in children with autism, the disorder is not characterized by a unitary language deficit. Phonological, lexical, semantic, and syntactic deficits vary widely in children with autism, with some exhibiting close to normal abilities while others show profound impairments (Lord & Paul, 1997; Kjelgaard & Tager-Flusberg, 2001). Language skills in school-age children with autism are excellent predictors of current function and an important predictor of future outcome (Rutter, 1970; Lord & Paul, 1997; Kobayashi, Murata & Yoshinaga, 1992; Venter, Lord & Schopler, 1992).

Given the pervasiveness of language disorders in children with autism, studies of very young children with autism that examine the early precursors to language would be of theoretical and clinical interest. Early precursors to speech and language have been well documented in typically developing infants and young children (Kuhl, 2000, 2004; Jusczyk, 1997). These studies demonstrate that typically developing infants have: (1) the ability to discriminate among the phonetic units of speech, (2) a keen interest in spoken language, and (3) the ability to learn from exposure to language.

Research on infants provides ample evidence that infants discriminate the phonetic units of speech, including both native- and foreign-language contrasts (Eimas, Siqueland, Jusczyk & Vigorito, 1971; Werker & Tees, 1984). Infants' early speech perception skills have recently been shown to be reliable predictors of future language abilities. Tsao, Liu and Kuhl (2004) demonstrated that individual variation in infants' speech discrimination skills at 6 months of age predicted their language abilities at three future points in time, 13 months, 16 months, and 24 months. Other evidence linking speech perception to language includes studies showing that the phonetic discrimination skills of children diagnosed with reading disorders (Reed, 1989; Manis *et al.*, 1997), dyslexia (Godfrey, Syrdal-Lasky, Millay & Knox, 1981), learning disabilities (Kraus *et al.*, 1996;

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Bradlow *et al.*, 1999), and specific language impairment (Leonard, McGregor & Allen, 1992; Tallal & Stark, 1981; Werker & Tees, 1987) are deficient when compared to control groups. These findings suggest that speech discrimination in preschool children with autism should be evaluated.

There is also growing evidence that language learning in typically developing infants may be enhanced by their social interest in speech, especially the kind of speech that is directed towards them, often called 'motherese.' Motherese is characterized by higher pitch, slower tempo, and exaggerated intonation contours (Fernald, 1985; Grieser & Kuhl, 1988). Infants given a choice show a preference for motherese as opposed to adult-directed speech (Pegg, Werker & McLeod, 1992; Cooper & Aslin, 1990; Werker & McLeod, 1989; Fernald, 1985; Glenn & Cunningham, 1983), a preference that is attributable to its pitch characteristics (Fernald & Kuhl, 1987).

Motherese has been argued to be beneficial to language learners (Karzon, 1985; Hirsh-Pasek *et al.*, 1987; Kemler Nelson, Hirsh-Pasek, Jusczyk & Cassidy, 1989; Fernald, 1985; Fernald & Kuhl, 1987). Studies show, for example, that infant-directed speech contains particularly good phonetic exemplars – sounds that are clearer, longer, and more distinct from one another – when compared to adult-directed speech (Kuhl *et al.*, 1997; Burnham, Kitamura & Vollmer-Conna, 2002). Further research shows an association between the clarity of a mother's speech when she talks to her infant and that infant's speech perception skills (Liu, Kuhl & Tsao, 2003). A social interest in speech might therefore be beneficial.

In typically developing children, these two factors – excellent speech discrimination and a social interest in speech – may be critical to early language learning. Cross-language studies on infants in the first year of life indicate that listening to ambient language alters speech perception at an early age, producing a more sophisticated pattern of perception (Kuhl *et al.*, 1992). Infant learning from exposure to language may depend on both an initial ability to discriminate phonetic units *and* an early interest in listening to speech.

What do we know about linguistic and social processing of speech in children with autism? Impairments in social and emotional information processing and a lack of social interest in communication, particularly speech, are well documented (Baron-Cohen, Tager-Flusberg & Cohen, 1993). Deficits in social orienting, such as the failure to orient to one's name, are evident in toddlers and preschool children with autism (Dawson *et al.*, 1998; Dawson *et al.*, 2004; Osterling & Dawson, 1994; Osterling, Dawson & Munson, 2002; Werner, Dawson, Osterling & Dinno, 2000), as are deficits in joint attention (Mundy, Sigman, Ungerer & Sherman, 1986; Osterling & Dawson, 1994). Tests of listening preferences in autistic, developmentally delayed and typically developing children show that while all groups choose a children's song over a pure tone, typical and developmentally delayed children choose their mother's voice over a recording of many superimposed voices, whereas children with autism select superimposed voices over their mother's voice (Klin, 1991, 1992).

A lack of attention to speech in children with autism is also shown in brain measures. Event-related potential studies suggest that high-functioning children with autism show differences in the P3, a brain component related to attention to important environmental stimuli (Courchesne, Kilman, Galambos & Lincoln, 1984; Courchesne, Lincoln, Kilman & Galambos, 1985; Dawson, Finley, Phillips & Galpert, 1986, 1988; Kemner *et al.*, 1995). Kemner *et al.* also examined the mismatch negativity (MMN), an ERP component elicited automatically by a stimulus change in a repeated sequence of stimuli. Using vowels, the authors reported significantly reduced amplitudes for the P3 in participants with autism, and no other significant effects. A recent study examined ERP responses to simple tones, complex tones, and synthetic vowels in high-functioning children with autism and typical school age children (Ceponiene *et al.*, 2003). The results showed that sensory processing (P1-N2-N4 complex) and speech discrimination (MMN) were comparable across groups, but that the P3 complex was abnormal for speech stimuli in children with autism. These studies indicate that high-functioning children with autism show typical MMN and other early ERP components in response to speech, but that the P3 is abnormal.

There are no data, however, that examine linguistic and social processing of speech signals in preschool children with autism. The present experiments were designed to fill that gap and had three goals. The first was to examine auditory preference in preschool children with autism spectrum disorder (ASD) and comparison samples of children using carefully matched speech and non-speech signals. None of the existing listening preference studies in children with autism attempted to match the acoustic characteristics of the signals being compared. We pitted motherese speech samples against non-speech analog signals derived from the motherese speech samples, matching their acoustic characteristics over time. We hypothesized that, given a choice, children with ASD would show a strong and significant preference for the non-speech analog signals, whereas the comparison children would not.

The second goal was to assess basic speech-discrimination abilities, as reflected by the MMN, in the same preschool ASD children. The use of an ERP design that maximized elicitation of the MMN allowed phonetic discrimination to be measured in young children with ASD without training.

The third goal was to examine potential associations between the linguistic and social measures, and between both measures and the severity of autism symptoms. No study has examined phonetic discrimination and listening preference in the same children with ASD. Previous work on typically developing children suggests that a social interest in speech plays a role in early speech learning (Kuhl, Tsao & Liu, 2003; Kuhl, 2003). The present study was designed to provide data on preschool children with ASD that assessed both linguistic and social speech processing.

Method

Participants

Participants were recruited from local parent advocacy groups, public schools, the Washington State Department of Developmental Disabilities, clinics, hospitals, and the University of Washington Infant and Child Subject Pool. Exclusionary criteria included the presence of a neurological disorder of known etiology (for ASD group only), significant sensory or motor impairment, major physical abnormalities, and history of serious head injury and/or neurological disease.

ASD group

Children with ASD were diagnosed using the Autism Diagnostic Interview – Revised (ADI-R) (Lord, Rutter & LeCouteur, 1994) and the Autism Diagnostic Observation Schedule – Generic (ADOS-G) (Lord *et al.*, 1989). Both assess the symptoms of autistic disorder listed in the *Diagnostic and Statistical Manual of Mental Disorders*, 4th edition (DSM-IV; American Psychiatric Association, 1994). Trained professionals also made a clinical judgment of diagnosis based on ASD symptoms as defined in the DSM-IV. For this study, children with autism met the criteria on the ADOS-G and ADI-R, as well as the DSM-IV criteria for autistic disorder based on clinical judgment. Children who met criteria on the ADOS-G and the DSM-IV clinical diagnosis, and came within two points of meeting criteria on the ADI-R, were also classified as children with autism. Children diagnosed as Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS) met criteria for PDD-NOS on the ADOS-G, met criteria for Autistic Disorder on the ADI-R or missed criterion on the ADI-R by two or fewer points, and met DSM-IV criteria for PDD-NOS based on clinical judgment. Using these criteria, 29 children with ASD were enrolled as participants in the study. These children were aged between 32 and 52 months ($M = 45.31$ months), 26 males and three females. An additional 28 children with ASD were excluded due to: insufficient numbers of ERP trials ($n = 18$), refusal to wear the electrocap ($n = 5$), failure to exhibit head-turns during the familiarization phase of auditory preference ($n = 3$), and equipment problems during ERP recordings ($n = 2$).

Typically developing comparison groups

The behavioral and electrophysiological methods used required two different comparison groups of typically developing children. Behavioral tests of auditory preference require a comparison group of typical children matched on the basis of mental age (TDMA). Groups were matched on mental age based on the composite score on the Mullen Scales of Early Learning (Mullen, 1984). Any child with typical development who exhibited unusually high or low cognitive ability as assessed by their composite score on the Mullen Scales of Early Learning (Mullen, 1984) was excluded. Mental age did not differ significantly in the final sample of ASD ($M = 29.28$, SD = 9.87) and TDMA participants ($M = 27.5$, SD = 9.42), nor in the two subgroups of ASD children who preferred motherese ($M = 29.36$, SD = 11.13) versus non-speech analogs ($M = 28.5$, SD = 9.35). All typically developing children were administered the ADOS-G and did not meet criteria for autistic disorder. Twenty-nine TDMA participants were tested on the auditory preference task; they were aged between 13 and 48 months ($M = 27.78$ months), 22 were males and seven were females. An additional three TDMA participants were excluded because of a failure to exhibit head-turns during the familiarization phase of the auditory preference test. Event Related Potential (ERP) studies require a comparison group of typically developing children matched on the basis of chronological age (TDCA). Fifteen TDCA children were tested in the ERP study of speech sound discrimination; they were aged between 33 and 70 months ($M = 48.33$ months), 13 were males and two were females.

Additional social and language measures were collected on the ASD and TDMA participants; they included joint attention from the Early Social Communication Scale (ESCS) (Seibert & Hogan, 1982) and expressive language from the Vineland Adaptive Behavior Scales (VABS) (Sparrow, Balla & Cicchetti, 1984). These measures, along with the social-communication total score from a diagnostic measure (ADOS-G), were used to assess potential relationships among the variables examined in the study.

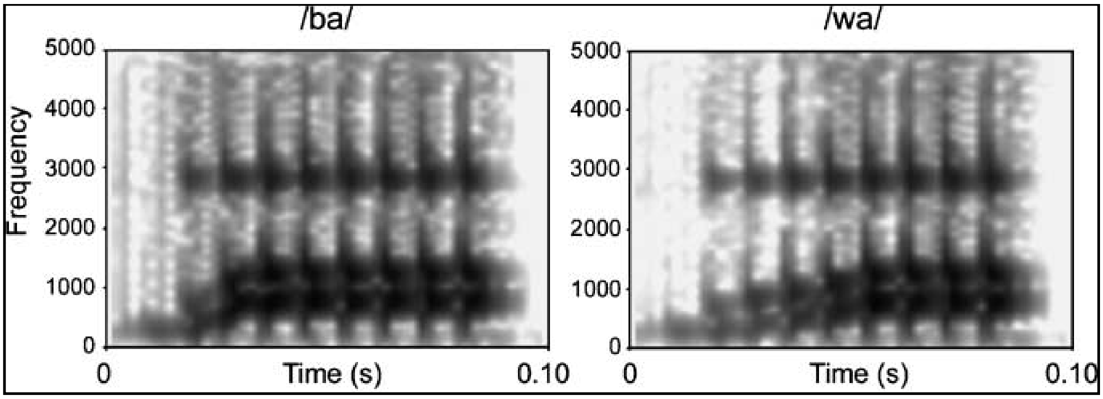

Figure 1 *ERP stimuli spectograms: /ba/ and /wa/.*

Stimuli

Event-related potential test

The speech stimuli were the consonant–vowel (CV) syllables /ba/ and /wa/ (Figure 1), computer synthesized to be identical except for the duration of the initial formant transitions, the critical acoustic information differentiating the two syllables (Pisoni, Carrell & Gans, 1983). The stimuli contained five formants and consist of a 20-ms period of low frequency, low amplitude pre-voicing, 15-ms (/ba/) or 45-ms (/wa/) formant transitions, and a steady state vowel. The F1 transition started at 234 Hz and rose linearly to 769 Hz. The F2 transition started at 616 Hz and rose linearly to a steady state value of 1232 Hz. F3, F4, and F5 were constant for the duration of the steady state vowel and were set at 2862 Hz, 3600 Hz, and 3850 Hz. The stimuli were 80 ms in duration.

Auditory preference test

Two sets of stimuli were used in the test for auditory preference. The speech stimuli consisted of eight samples of infant-directed (ID) speech that were recorded in a previous experiment conducted in our laboratory (Kuhl *et al.*, 1997). The non-speech analogs of the speech samples were created specifically for the present experiment. The speech samples were recorded from five adult women as they spoke to their infants and were between 4.8 and 5.3 seconds in duration (Kuhl *et al.*, 1997). To create the non-speech analogs, the speech samples were analyzed to derive their formant frequencies and amplitudes over time; these values were used to create computer synthesized non-speech analogs whose sine-wave components matched the formants of the original samples in frequency and amplitude.

Design

Event-related potential test

The ERP study employed a repeated measures design, with stimulus, hemisphere and electrode site as the within-subject factors, and experimental group and preference for speech versus non-speech analogs as the between-subject factors. The dependent measures were peak amplitude, peak latency, and the ERP difference wave.

Auditory preference test

The behavioral experiment employed a 2 × 2 factorial design, with side of presentation for speech and non-speech signals (left versus right) and familiarization order (speech first versus non-speech first) as between-subject variables. The dependent measure was the percentage of trials in which the participant's head-turn was in the direction required to produce non-speech analogs. Participants were assigned randomly to each of the groups.

Apparatus

Event-related potential test

EEG was collected continuously from 19 electrode sites using the standard international 10/20 system. Participants wore an elastic Electro-cap, and data was acquired using Neuroscan Synamps. Participants listened passively while sitting in a comfortable chair watching a video of their choice with very low volume. The speech stimuli were presented from a speaker placed in front of the participant below the video monitor.

Auditory preference test

Participants sat on a parent's lap at a table in a three-sided enclosure. Loudspeakers with miniature lights attached were located in the left and right panels of the enclosure. The center panel contained openings for a color television and a video camera. A control room housed a video-cassette recorder that fed images to the television in the test enclosure. A custom-designed interface interrupted the video and was controlled by the experimenter who observed the participant via a video monitor. The audio stimuli, reproduced with 10 000 12-bit samples per second and low-pass filtered with a 4.6 KHz cut-off frequency, were controlled by the computer.

Procedure

Event-related potential test

The task was an oddball paradigm designed to elicit the MMN, with /wa/ (standard) occurring 85% of the time and /ba/ (deviant) the remaining 15% of the time. Signals were presented at 67 dBA. The inter-stimulus interval was 920 ms, offset to onset. Participants heard a minimum of 500 syllables. All data were processed off-line, using epochs of 50 ms pre-stimulus and 500 ms post-stimulus onset. Standards immediately following deviants were excluded from analysis. Trials were hand-edited to ensure artifact-free data. Finally, data was filtered using a low-pass filter with a cut-off of 25 Hz. Grand averages of the ASD and TDCA groups were examined to determine the measurement windows. As predicted in this situation, no P3 was observed for either TDCA or ASD groups. Peak negative amplitude and peak latency measurements were taken at 250–400 ms to assess MMN at lateral electrode sites, F3/4, F7/8, T3/4, and C3/4.

Auditory preference test

Parents were asked to keep the child centered and oriented forward. The experiment began with four familiarization trials that alternated between the speech and non-speech signals. When the experimenter judged that the participant was at midline, the video was interrupted and the lights were manually activated on one side of the test booth. Participants were required to spontaneously turn their heads toward the lights to begin the signal presentation. After completion of the signal, the lights were turned off and the video turned on until the participant was again at midline, which allowed the initiation of a new trial.

Following four familiarization trials, the test phase began. For test trials, sound presentation was contingent upon a 30-degree head-turn to the right or left. When the experimenter judged that a head-turn had occurred, the signal was presented, accompanied by lights. Speech and non-speech stimuli were assigned to left and right sides in a counter-balanced fashion. The eight speech and non-speech signals were each presented twice in random order during the test phase for a total of 16 trials. Participants who did not complete five trials were eliminated. Signals were presented at 70 dBA.

Results

Group analysis

Event-related potential test

Measurements were taken for peak negativity and latency in the 250–400 ms time window for each subject in both groups. Windows for measurement were determined after examining grand averages for standards, deviants and difference waves. Measurements of the most negative peak were taken in the area in which the greatest difference between standards and deviants occurred. Children with fewer than 25 deviants in their average were excluded from further ERP analysis. The mean number of deviants for the ASD group was 39 (range = 25–57); the mean number of deviants for the TDCA group was 40 (range = 29–51), a difference that was not significant ($p > .10$). Repeated measures analyses of variance were completed on data obtained from eight lateral electrode sites for each group, examining the effects of stimulus, hemisphere, and electrode site as within-subject factors.

As expected, TDCA children showed a strong stimulus effect for peak amplitude, $F(1, 14) = 20.199$, $p = .001$, with the deviant being significantly more negative than the standard (Figure 2). Significant hemisphere effects were also present with the right hemisphere significantly more negative than the left, $F(1, 14) = 15.732$, $p = .001$. In addition, there was a significant stimulus by hemisphere interaction, $F(1, 14) = 7.601$, $p = .015$. Peak amplitude of the standard was similar across hemispheres while deviant peak amplitudes were more negative in the right hemisphere. There were no significant effects for peak latency.

In contrast, children with ASD showed no significant stimulus, hemisphere or interaction effects for peak amplitude or peak latency (Figure 3). A repeated measures analysis of variance comparing the two groups revealed a significant group effect, $F(1, 42) = 7.908$, $p = .007$, for peak amplitude. There was also a significant group by hemisphere interaction, $F(1, 42) = 4.583$, $p = .038$. Mean peak amplitude was similar across hemispheres for children with ASD, but significantly more

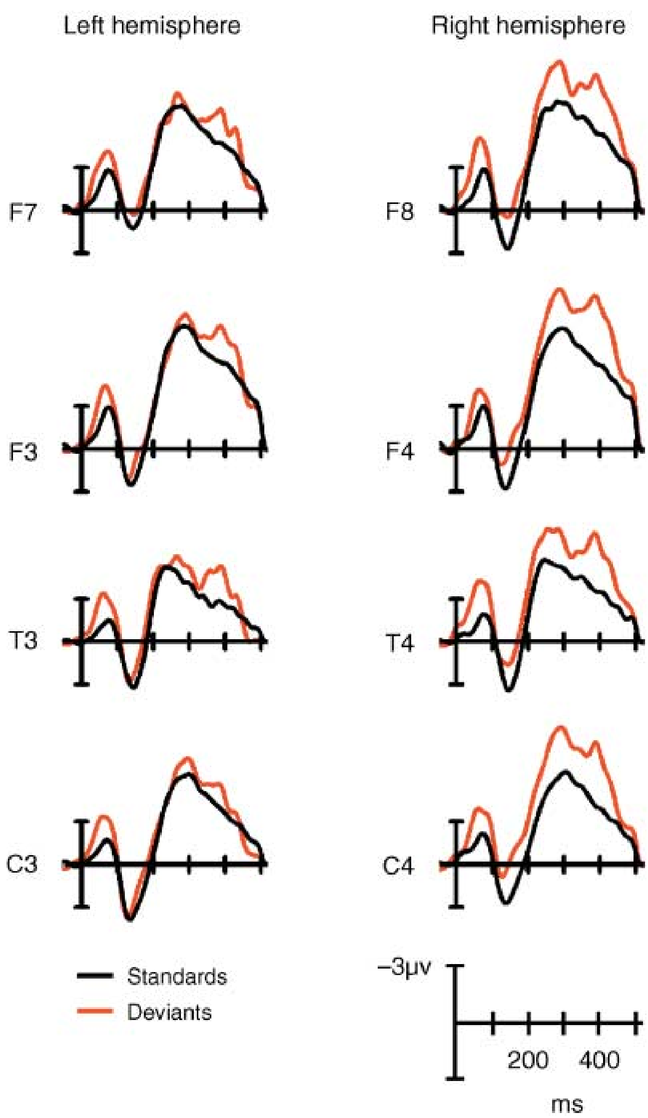

Figure 2 *TDCA participants:* n = *15. Significant peak amplitude effects for stimulus* (p = *.001), hemisphere* (p = *.001), and stimulus by hemisphere interaction* (p = *.015).*

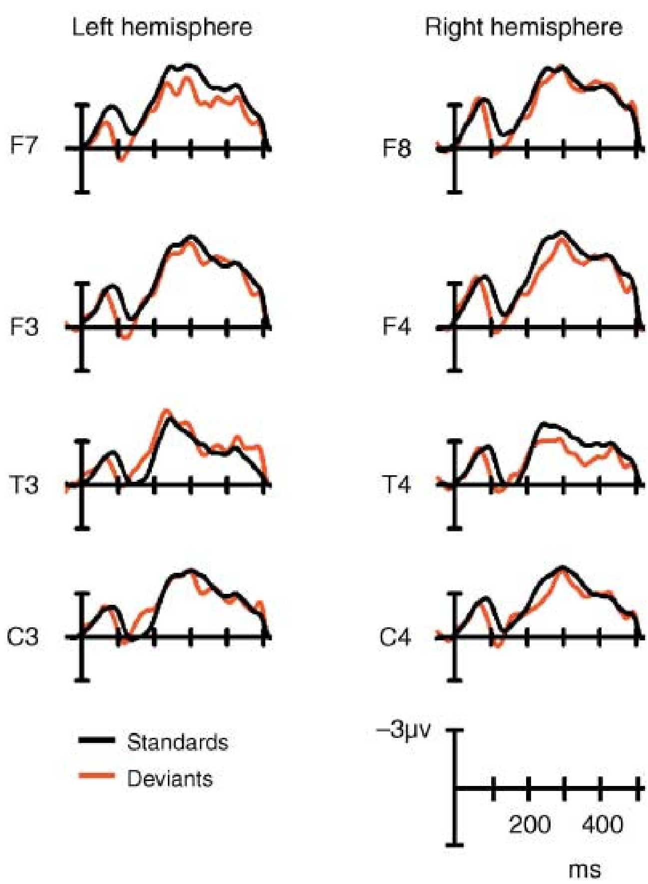

Figure 3 *Children with ASD:* n = *29. Peak amplitude effects for stimulus and hemisphere are not significant.*

negative in the right hemisphere for TDCA participants. There were no significant group effects for peak latency.

Auditory preference test

As predicted, children with ASD demonstrated a strong listening preference for the non-speech analog signals. A *t*-test comparing the percentage of head-turns in the direction of the non-speech signals (M = 61.57%) exceeded chance (M = 50%), $t(28) = 2.310$, $p = .028$. Of the 27 children with ASD who exhibited a preference for one of the two signals, 20 (74%) exhibited a preference for the non-speech signals, significantly greater than 50% chance, $p = .021$ (binomial). TDMA participants did not demonstrate a listening preference. A *t*-test comparing the mean percentage of head-turns in the direction of non-speech analogs (M = 47.52%) to chance performance (M = 50%) revealed no significant difference between means, $t(28) = -.471$, $p = .642$. Of the 21 typical participants who exhibited a preference for one of the two kinds of signals, 11 (52%) turned more often toward the non-speech signals, consistent with chance, $p = 1.000$ (binomial). A one-way analysis of covariance controlling for the effects of mental-age showed a significant group difference for percentage of head-turns in the direction of non-speech analogs, $F(1, 55) = 4.386$, $p = .041$. There were no significant effects for side of presentation of non-speech analogs ($F(1, 56) = 1.093$, $p = .300$) or for familiarization direction ($F(1, 56) = 2.278$, $p = .137$).

Subgroup analyses

Listening preference was used to assign children with ASD into subgroups. Seven children with ASD preferred

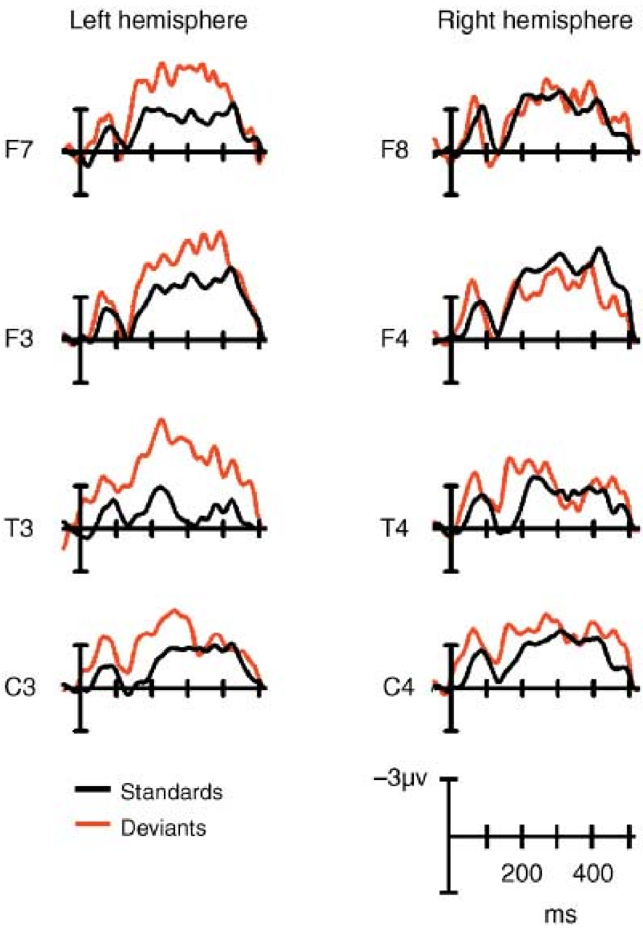

Figure 4 *Children with ASD who prefer speech:* n = *7. Significant peak amplitude effects for stimulus (*p = *.032).*

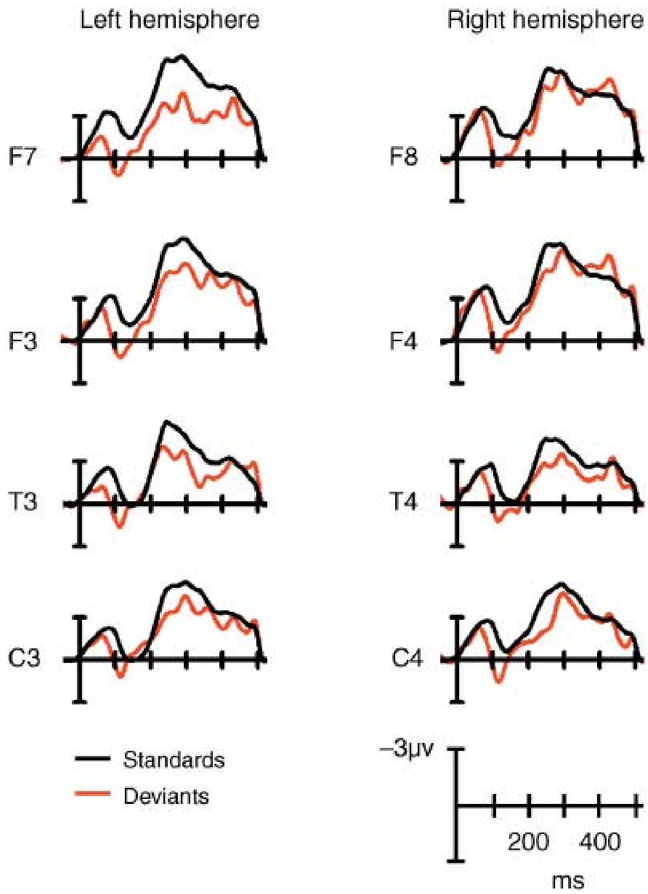

Figure 5 *Children with ASD who prefer non-speech analogs:* n = *20. Peak amplitude effects for stimulus are not significant. Significant stimulus by hemisphere interaction (*p = *.008).*

the motherese speech signals. These participants were aged between 32 and 52 months ($M = 44.71$ months), six males and one female. Twenty children with ASD preferred the non-speech analog signals. These participants were aged between 38 and 52 months ($M = 45.51$ months), 18 males and two females. The mean number of deviants for the ASD group who preferred speech was 41 (range = 31–57); the mean number of deviants for the ASD group who preferred non-speech analogs was 38 (range = 25–51), a difference that was not significant ($p > .10$). Two ASD participants did not exhibit a preference and were excluded from further analyses. Independent ERP analyses of the two subgroups of children with ASD (i.e. prefer speech versus prefer non-speech analogs) revealed strikingly different patterns.

Waveforms for the children with ASD who preferred speech appeared more similar to the age-matched controls than waveforms for the children with ASD who preferred non-speech analogs (Figure 4). ASD participants who preferred speech displayed an overall stimulus effect for peak amplitude, $F(1, 6) = 7.780$, $p = .032$. These participants showed a large difference between the peak amplitudes of standards and deviants bilaterally, with the deviants showing increased negativity. There were no significant peak latency effects.

Waveforms for the children with ASD who preferred non-speech analogs revealed no significant overall stimulus effect for peak amplitude (Figure 5). There was a strong stimulus by hemisphere interaction for peak amplitude, $F(1, 19) = 8.928$, $p = .008$. Although the TDCA participants also exhibited a significant stimulus by hemisphere interaction, the underlying patterns were very different. As is evident in Figure 6, this subgroup of ASD participants exhibited a positivity for deviants in the left hemisphere. Deviants were more negative than standards in the right hemisphere at frontal sites, but the difference was far smaller than for either of the other groups. There was also a significant stimulus effect for peak latency for this subgroup, $F(1, 19) = 4.403$, $p = .049$, with shorter peak latencies for standards.

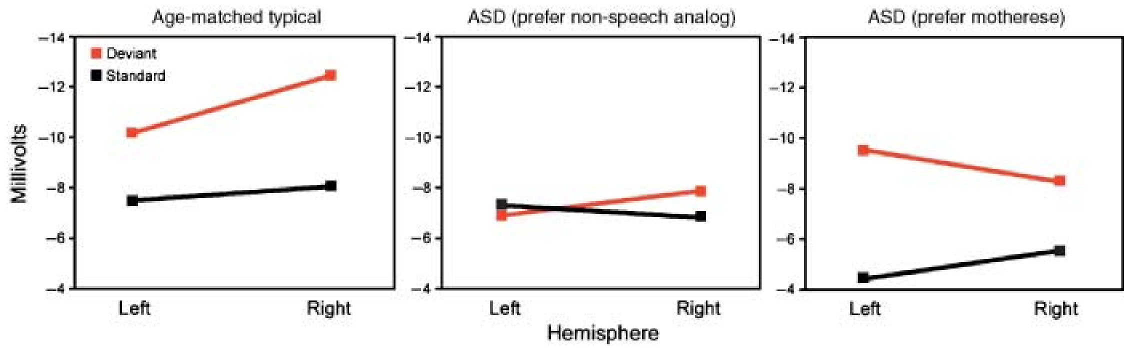

Figure 6 *TDCA comparison children: significant stimulus by hemisphere interaction (*p *= .015); Children with ASD who prefer non-speech analogs: significant stimulus by hemisphere interaction (*p *= .008); Children with ASD who prefer speech: non-significant stimulus by hemisphere interaction.*

The relationship among the three participant groups (children with ASD who prefer speech, children with ASD who prefer non-speech analogs, and TDCA comparison children) was examined with a repeated measures analysis of variance. Within-subject factors were stimulus, hemisphere, and electrode site and the between-subject factor was group. There was a significant group effect for peak amplitude, $F(2, 39) = 3.308$, $p = .047$. *Post hoc* tests using Dunnett's pair-wise multiple comparison *t*-test, comparing multiple treatments against a single control, revealed a significant difference between the TDCA children and children with ASD who prefer non-speech analogs ($p = .046$), and no significant difference between TDCA children and children with ASD who prefer speech ($p = .103$). A significant stimulus by hemisphere by group interaction, $F(2, 39) = 4.589$, $p = .016$, was also obtained due to the fact that TDCA children and children with ASD who prefer speech were very similar, while children with ASD who prefer non-speech analogs were dramatically different. There were no significant group effects for latency.

Correlations

Children with ASD exhibited significant positive correlations between percent preference for non-speech analogs and number of autism symptoms, as reflected in the social-communication total of the ADOS-G, $r_s = .388$, $p = .037$, $n = 29$ (Figure 7). Participants with a strong preference for non-speech analogs tended to have more symptoms of autism (i.e. higher ADOS scores). Significant negative correlations were observed between per cent preference for non-speech analogs and a measure of frequency of initiations of joint attention from the Early Social Communication Scales (ESCS), $r_s = -.414$, $p = .036$, $n = 26$ (Figure 8); moreover, a significant relationship was observed between per cent preference for non-

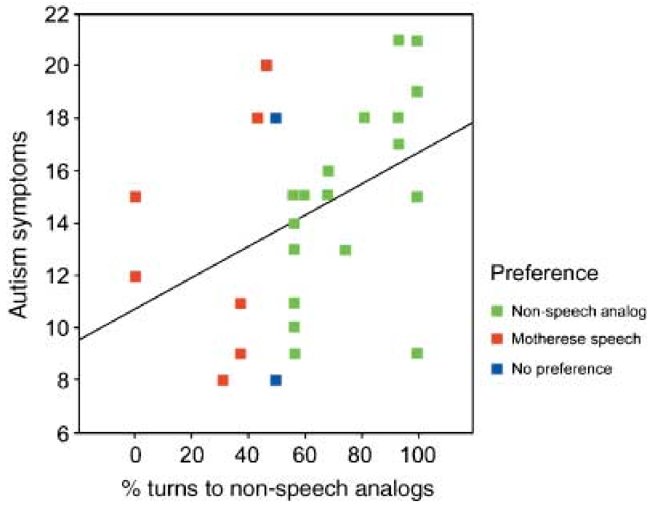

Figure 7 *Children with ASD: scatter plots relating autism symptoms (ADOS social-communication total) and per cent head-turns to non-speech analogs ($r_s = .388$,* p *= .037,* n *= 29).*

speech analogs and the Vineland Expressive Language subscale age equivalent, $r_s = -.370$, $p = .048$, $n = 29$ (Figure 9). Participants with a strong preference for non-speech analogs tended to score lower on measures of initiating joint attention and expressive language. Typical participants did not exhibit significant relationships between per cent preference for non-speech analogs and any of these measures.

The relationships between per cent preference for non-speech analogs and peak amplitude and peak latency of the ERP difference waves were examined for the children with ASD. There was a significant positive correlation between preference for non-speech analogs and peak amplitude of the difference wave at T3, $r_s = .414$, $p = .025$, $n = 29$ (Figure 10). Participants with a strong preference for non-speech analogs tended to have less

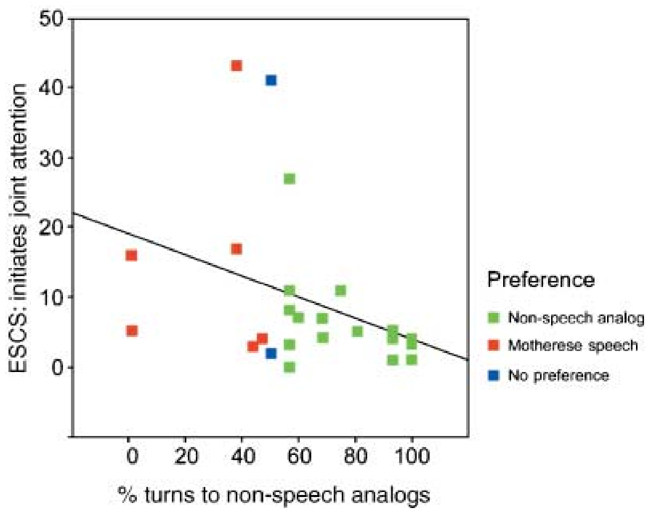

Figure 8 *Children with ASD: scatter plots relating frequency of initiations of joint attention from the Early Social Communication Scales (ESCS) and per cent head-turns to non-speech analogs* (r_s = *–.414,* p = *.036,* n = *26).*

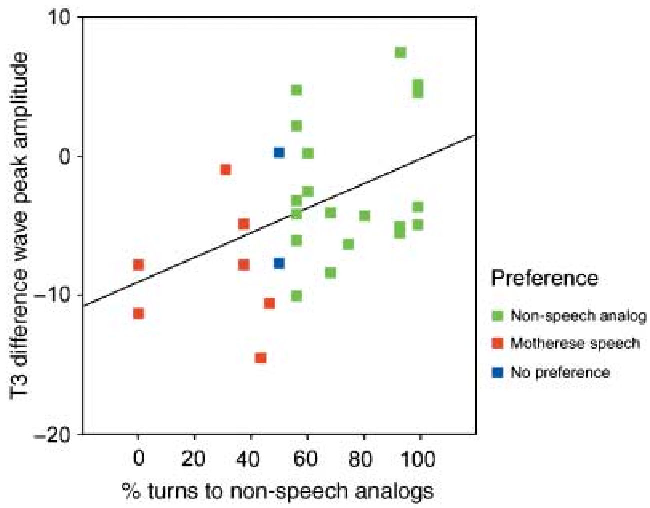

Figure 10 *Children with ASD: scatter plots relating T3 difference wave peak amplitude and per cent head-turns to non-speech analogs* (r_s = *.414,* p = *.025,* n = *29).*

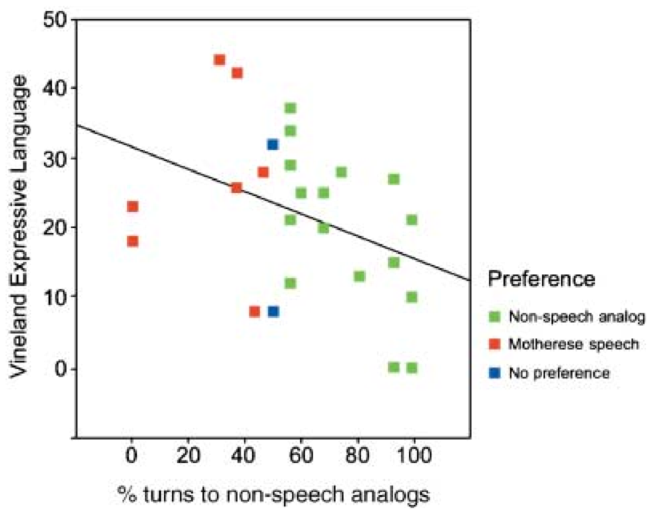

Figure 9 *Children with ASD: scatter plots relating Vineland Expressive Language subscale and per cent head-turns to non-speech analogs* (r_s = *–.370,* p = *.048,* n = *29).*

negative peak amplitudes, indicating less discriminative capacity.

Discussion

The results provide three novel findings on preschool children with autism spectrum disorder. First, group comparisons reveal that preschool-aged children with ASD differ significantly from typically developing comparison children, both in their neural and in their behavioral responses to speech. Children with ASD, as a group, did not exhibit the MMN in response to a change in speech syllables, whereas typically developing children exhibited the expected MMN. Second, and as predicted, children with ASD, as a group, exhibited a significant listening preference for non-speech analog signals that, while matched acoustically to motherese speech samples, resembled computer warbles. Typically developing children do not prefer these non-speech analog signals. Third, when listening preference was used to separate the children with ASD into two groups – those who prefer non-speech signals versus those who prefer motherese speech – different neural patterns in response to speech were found for the two subgroups. Specifically, it was found that the brain waves of children with ASD who prefer motherese resemble those of typically developing children, exhibiting the MMN to a syllabic change, while those of children with ASD who prefer non-speech continue to show the aberrant ERP pattern.

The lack of an MMN in children with ASD with the most severe symptoms of autism suggests the potential for central auditory deficits that affect a listener's ability to register an auditory change in a speech stimulus. The findings are consistent with those obtained through a variety of measures in diverse populations with language/learning impairments (Kraus *et al.*, 1996; Bradlow *et al.*, 1999). Future studies in preschool-aged children with ASD will focus on careful comparisons between speech and non-speech in the elicitation of the MMN to determine whether all complex auditory signals fail to evoke the MMN or whether speech signals alone fail to elicit the MMN. We are following these children longitudinally and will be able to examine whether these early measures are predictive of later language acquisition in autism.

Regarding the finding that children with ASD prefer non-speech signals, careful control of the signals rules out the alerting value of specific acoustic components (those with high frequencies) in explaining the observed preferences. Taken together with previous studies using a variety of social and non-social auditory stimuli, the atypical listening preference of children with ASD suggests that they actively prefer sounds emanating from non-human rather than human sources. Whether speech can be altered so as to make it more interesting to children with autism will be a focus in future research.

Tests of association show high positive correlations between the social measure (a listening preference for non-speech) and the linguistic measure (ERP brain measures of speech discrimination ability). Moreover, strong patterns of association are obtained for both the linguistic measure and the social measure when compared with various diagnostic scales of autistic spectrum disorder. The patterns of correlation are very consistent – atypical speech processing scores are strongly and positively associated with greater severity of autism.

These findings have two broader implications for children with autism. First, group measures can underestimate individual children's skills. The preschool-aged children with ASD tested here varied greatly in their linguistic and social processing of speech. Some children with ASD demonstrated typical neural patterns in response to speech and typical social responsiveness to speech. As shown, the two speech measures correlate strongly with the diagnostic assessment of autism severity. Ongoing studies in our laboratory are now using these speech measures as potential predictors of success in an early intervention program for toddlers with ASD.

Second, the results of the present study suggest an associative link between phonetic and social speech processing in children with ASD. Recent studies on typically developing infants provide support for the idea that social factors play a role in language acquisition. Kuhl, Tsao and Liu (2003) demonstrated that when 9-month-old American infants are exposed to a foreign language for the first time during natural social interaction with native-speaking Chinese speakers, they readily learned to discriminate a phonetic contrast that control infants, unexposed to the foreign language, were unable to discriminate. However, when the same foreign-language material was presented via video or audiotape, no phonetic learning occurred, suggesting that phonetic learning in infancy may rely on social interaction. Moreover, social feedback appears to enhance speech production development – when infants' vocalizations are followed by parental social interaction that is either contingent or non-contingent on infants' vocalizations, infants who experience contingent feedback increased both the quantity and quality of their vocalizations (Goldstein, King & West, 2003; Kuhl, 2003). Children with autism, who lack a social interest in communication, may be at a distinct disadvantage in language learning based on social factors.

The present data suggest that phonetic and social speech processing abilities – skills that are prevalent and well documented in typically developing infants – might serve as highly sensitive markers of ASD in preschool children. Speech measures can be used with young infants, making early speech measures a potential target of opportunity for the identification of very young children with autism.

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