Published in final edited form as:
J Speech Lang Hear Res. 2010 August ; 53(4): 1052–1064. doi:10.1044/1092-4388(2009/09-0096).

Behavioral and Physiological Responses to Child-Directed Speech as Predictors of Communication Outcomes in Children with Autism Spectrum Disorders

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Abstract

Purpose—To determine the extent to which behavioral and physiological responses during child-directed speech (CDS) correlate concurrently and predictively with communication skills in young children with autism spectrum disorders (ASD).

Method—Twenty-two boys with ASD (initial mean age of 35 months) participated in a longitudinal study. At entry, behavioral (i.e., percent looking) and physiological (i.e., vagal activity) measures were collected during CDS stimuli. A battery of standardized communication measures was administered at entry, and re-administered 12 months later.

Results—Percent looking during CDS was strongly correlated with all entry and follow-up communication scores; vagal activity during CDS was moderately to strongly correlated with entry Receptive Language, and follow-up Expressive Language and Social-Communicative Adaptive Skills. After controlling for entry communication skills, vagal activity during CDS accounted for significant variance in follow-up communication skills, but percent looking during CDS did not.

Conclusions—Behavioral and physiological responses to CDS are significantly related to concurrent and later communication skills of children with ASD. Further, higher vagal activity during CDS predicts better communication outcomes 12 months later, after accounting for initial communication skills. Further research is needed to better understand the physiological mechanisms underlying variable responses to CDS among children with ASD.

As a group, children with autism spectrum disorders (ASD) are at high risk for severe delays and lifelong impairments in broad aspects of language competency (Lewis, Murdoch & Woodyatt, 2007; Loucas et al., 2008; Mawhood, Howlin & Rutter, 2000). Early intervention to facilitate language development among young children with ASD is recommended due to the strong associations between language skills and later functional outcomes (Luyster, Qiu, Lopez & Lord, 2007; Szatmari, Bryson, Boyle, Streiner & Duku, 2003; Venter, Lord & Schopler, 1992). Recently, the links between prelinguistic communication and later outcomes of children with ASD have garnered more attention. An increased understanding of prelinguistic factors that predict preschool language development in children with ASD could lead to improved communication assessment and early intervention strategies in this population.

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One striking, replicated finding related to the prelinguistic development of children with ASD documents their low behavioral responsiveness to speech. Infants and toddlers with ASD are less responsive to a name call (Baranek, 1999; Lord, 1995; Osterling Dawson & Munson, 2002), and do not show the expected preferences for mother's voice and child-directed speech (CDS) over other stimuli (Klin, 1991; Kuhl, Coffrey-Corina, Padden & Dawson, 2005; Paul, Chawarska, Fowler, Cicchetti, & Volkmar, 2007). The implications of this limited responsiveness for later language and social-communicative outcomes may be significant. Response to CDS can be measured both behaviorally and physiologically, to capture different aspects of attention quality. The purpose of this paper is to examine concurrent and predictive associations of behavioral and physiological responses during CDS with language and social-communication skills of children with ASD. To provide important background for the study, we will review the characteristics of CDS along with its relation to child language acquisition; the evidence for decreased attention to CDS among children with ASD; vagal activity measures as physiological indices of attention quality; and the vagal system in children with ASD.

Child-Directed Speech

CDS is characterized by many differences when compared to adult-directed speech, including higher pitch, greater pitch range, shorter sentences, elongated vowels, more repetition, less diversity in vocabulary, and more references to the "here-and-now" (for a review, see Pine, 1994). CDS is posited to play several important roles in child-caregiver interactions. First, the features serve to promote the affective relationship between adults and young children (Trevarthen & Aitken, 2001), as supported by findings that infants show more positive affect in response to CDS than to adult-directed speech (Fernald, 1993; Werker & McLeod, 1989). Second, CDS selectively engages the attention of typically developing children, who prefer CDS to adult-directed speech as early as one month of age (e.g., Cooper & Aslin, 1990), and continue these preferences into the toddler (Kuhl et al., 2005; Paul et al., 2007) and preschool years (Klin, 1991). In addition to enhanced attention, infants show enhanced neural responses to words spoken with intonations associated with CDS compared to the intonations used in adult-directed speech (Zangl & Mills, 2007). The third important role is that CDS appears to enhance children's language learning. For example, recent evidence demonstrated that features of CDS assist infants in detecting word boundaries (Thiessen, Hill & Saffran, 2005), and in learning language-specific phonetic categories (Werker et al., 2007). Thus, children seem to respond to CDS by preferentially attending to it in a context of positive affect. This behavioral response pattern to CDS is associated with enhanced neural responses, and more efficient learning of some language features than occurs when children are exposed to speech that does not have CDS features.

Impairment of Attention to CDS in Children with ASD

As noted above, children with ASD do not attend to CDS to the extent that other young children do. Diminished attention to CDS among these children will reduce their opportunities to benefit from its unique features. What, then, may explain decreased attention to CDS among children with ASD? Some explanations may lie in the different components of attention that could be impaired when children with ASD are exposed to CDS. A primary component of attention is orienting, which is conceptualized as an involuntary, reactive phase of attention that occurs immediately following the onset of a novel stimulus (Posner & Petersen, 1990; Richards, 1987). In terms of neurological processing, orienting has been associated with a more posterior brain system (Posner & Petersen, 1990). The failure of children with ASD to respond promptly to name call (and other forms of CDS) likely reflects deficits in orienting. Obviously, orienting to stimuli is an important step in sensory processing and attention, and the failure of children with ASD to orient quickly and reliably may result in less time spent attending to CDS over time. Even if a child with ASD initially orients to CDS, a failure to maintain attention to likely would prevent the child from accruing benefits from exposure to CDS.

Beyond reactive orienting, the maintenance of attention to particular stimuli is considered “voluntary,” and has been associated with a more anterior brain system that regulates attention through cognitive control (Posner & Petersen, 1990; Richards, 1987). The current investigation examines individual variability among young children with ASD in sustaining attention to CDS, with the assumption that such sustained attention will underlie the learning necessary for effective social-communicative functioning. This assumption is supported by the findings of two investigations involving young participants with ASD. In a study of preschoolers by Kuhl et al. (2005), a subgroup of preschoolers with ASD who preferred CDS to a nonspeech analog showed better performance in a speech discrimination task than their counterparts with ASD who preferred to listen to nonspeech stimuli. Another recent study of toddlers with ASD found significant concurrent and predictive relations between attention to CDS and receptive language abilities (Paul et al., 2007). In the predictive analyses, however, Paul and colleagues did not partial out the association between receptive language at age two and receptive language at age three, leaving open the possibility that attention to CDS does not account for any unique variance in later language skills once initial language levels are taken into account. Thus, the degree to which attention to CDS accounts for later language skills in children with ASD is not yet clear.

Physiological Bases of Attention

Attention skills, as all behaviors, have underlying physiological bases which can be measured and examined for variability. For example, behavioral indications of sustained attention, such as quieting and looking, are associated with physiological changes, such as a slowing of heart rate. Researchers have concluded that heart rate changes during attention are mediated more by the parasympathetic (i.e., “rest and digest”) than the sympathetic (i.e., “fight or flight”) system (Richards & Casey, 1991). The influences of the parasympathetic system on the heart often are studied through measuring respiratory sinus arrhythmia (RSA) as an index of vagal activity. In a resting state, heart rate varies depending on the phase of the respiratory cycle, with an increase in heart rate on inspiration and a decrease in heart rate on expiration. The difference between the heart rate during inspiration versus expiration reflects the extent of influence of the vagus nerve in regulating the heartbeat. A larger difference (i.e., higher RSA) presumably reflects higher vagal activity and a smaller difference (i.e., lower RSA) lower vagal activity.

Higher RSA under nonchallenging, calm conditions has been associated concurrently and prospectively with a variety of child behavioral characteristics. For example, in infancy, higher baseline RSA is associated with more emotional reactivity, including more crying in response to mildly frustrating events and positive affective reactivity to social interactions; longitudinally, higher baseline RSA in infancy predicts greater sociability during the toddler and preschool years (e.g., Fox, 1989; Porges, Doussard-Roosevelt, Portales & Suess, 1994). Beauchaine (2001) suggested that RSA in infancy reflects the infant’s capacity for engagement with the environment, with high RSA associated greater behavioral, attentional and emotional responsiveness. Thus, high levels of infant responsiveness can be evidenced in more extreme *negative* and *positive* emotional reactions, but leads to better adaptation over time. Among preschoolers, higher resting RSA is related to higher concurrent social competence, better emotion regulation, and lower levels of problem behavior (Blair & Peters, 2003; Calkins, 1997; Doussard-Roosevelt, McClenny & Porges, 2001; Porges et al., 1994). As discussed by Beauchaine (2008), greater vagal influences on the heart also appear to protect children from developing psychopathologies associated with varying environmental risk factors. In general, then, higher resting RSA is associated with more positive developmental and social-emotional outcomes.

Recent work has focused on the adaptive function of vagal cardiac control in response to challenge. According to Porges' (1995) Polyvagal Theory, sensitive adjustments in vagal input to the heart, both up and down, provide an individual with the physiological resources needed to engage appropriately with the environment in the face of changing demands. "Polyvagal" refers to the different branches of the vagus, i.e., the myelinated and phylogenetically more recent ventral vagal complex, and the unmyelinated and phylogenetically older dorsal vagal complex. Porges (2007) argues that the ventral vagal complex is linked to behavioral functions of social communication, self-soothing, and calming. Further, he argues that RSA largely reflects the influences of the ventral vagal complex on the heart, and that the vagus is part of a complex neurophysiological system involving bidirectional influences between the cortex and brainstem operating in service of social engagement. Social affiliative responses to another person require sustained attention which is accompanied by decreased heart rate and greater vagal cardiac control. In contrast, in challenging, stressful, or threatening encounters, vagal control of the heart is diminished or withdrawn and sympathetic nervous system influences accelerate heart rate as the individual reacts with a fight or flight response. A number of studies support Porges' theory in that increased vagal regulation has been associated with better social skills and fewer behavior problems (Calkins & Keane, 2004; Doussard-Roosevelt, Montgomery & Porges, 2003), and a greater capacity for focused attention (Bornstein & Suess, 2000). Most studies of vagal regulation have compared baseline RSA with conditions involving negative stressors or cognitive challenges to determine the extent to which vagal influences on the heart are suppressed in response to challenges. When studies have contrasted negative social stressors with positive social interactions, however, results have indicated that RSA decreases in response to negative social stressors and increases in response to positive social interactions (Bazhenova, Plonskaia & Porges, 2001; Doussard-Roosevelt, Montgomery & Porges, 2003). Therefore, levels of and change in RSA (both increases and decreases) can index a child's awareness of the environment, affective reactions to the environment, and, potentially, responsiveness to CDS.

The Vagal System and ASD

Existing work suggests that children with ASD have reduced levels of resting RSA compared to controls (Ming, Julu, Brimacombe, Connor & Daniels, 2005), as well as diminished vagal adaptation to tasks with cognitive demands (Althaus, van Roon, Mulder, Mulder, Aarnoudse & Minderaa, 2004; Toichi & Kamio, 2003). Participants in these studies have been school-aged children and older adolescents; thus, the generalizability of these findings to toddlers or preschoolers with ASD has not been determined. Sigman and colleagues (Sigman, Dissanayake, Corona, & Espinosa, 2003) found that preschool children with autism did not differ from children with other developmental delays (DD) in their amount of looking at videos of a baby crying versus a baby playing happily, and also did not differ in heart rate in response to the two videos; however, these investigators did not use RSA, which is considered to be a better index of vagal cardiac control than is heart rate. No previous research has examined the extent to which variability in RSA among young children with ASD may predict later social-communicative outcomes.

Purpose of the Study

The over-arching focus of this study was to examine the association between behavioral and physiological responses to CDS on the one hand, and concurrent and later communication skills in young children with ASD on the other hand. We chose to measure these responses under non-demanding conditions, corresponding to descriptions of CDS as studied in other research—i.e., the special features of CDS are assumed to arise in part from adults' efforts to establish positive affective relations with a young child. Further, we included a contrasting nonsocial condition judged as likely to engage the children's attention in order to test the specificity of behavioral and physiological measures collected during CDS as predictors of language outcomes. Our research questions were as follows:

1. What is the relationship of behavioral and physiological responses during CDS or nonsocial stimuli, to concurrent communication skills in young children with ASD? Our hypotheses were:
    - **a.** Amount of looking during CDS stimuli (but not during nonsocial stimuli) will be positively correlated with concurrent measures of communication skills.
    - **b.** Vagal tone during CDS stimuli (but not during nonsocial stimuli) will be positively correlated with concurrent measures of communication skills.

      Rationale: (a) A child who looks more during CDS stimuli has more opportunities to benefit from its features, and to associate words with the objects or events they represent, and thus is likely to have better communication and language skills. (b) Both the nonsocial and CDS conditions in this study both were designed to be non-stressful and non-demanding. We posited that RSA during the nonsocial condition would not reflect the child’s inclination to respond to CDS positively, whereas RSA during CDS would index the extent to which a child attends to CDS with a positive affective response (c.f. Beauchaine et al., 2007). We propose that this physiological measure reflects a qualitative dimension of the child’s attention to CDS that will influence his or her tendency to learn efficiently from exposure to CDS.
2. Are behavioral or physiological responses during CDS or nonsocial stimuli predictive of communication outcomes in young children with ASD one year later, after controlling for initial communication skills? Our hypotheses were:
    - **a.** Looking during CDS stimuli (but not during nonsocial stimuli) will account for a significant amount of variance in communication outcomes one year later, with a greater amount of looking during CDS predicting better communication outcomes.
    - **b.** RSA during CDS stimuli (but not during nonsocial stimuli) will account for a significant amount of variance in communication outcomes one year later, with higher RSA during CDS predicting better communication outcomes.

      Rationale: Although adults decrease in the extent to which they use features of CDS as children grow older and their language production and comprehension skills become more sophisticated (e.g., Snow, Perlman & Nathan, 1987), we assumed that these children, whose skills were initially at or below a 24-month language age equivalent, were at a stage of language acquisition at which the special features of CDS would continue to have a beneficial impact, if the children attended to CDS. Thus, we hypothesized that the quantity of attention to CDS (measured behaviorally via looking) and quality of attention to CDS (measured physiologically via RSA) would each have a positive association with outcomes one year later, even after controlling for initial language abilities.

Method

Participants

Twenty-two boys diagnosed with ASD participated in this longitudinal study (see Table 1). Inclusion criteria included an existing diagnosis of autism by a licensed psychologist or physician, an expressive communication age equivalent (AE) of less than 24 months at entry, absence of a co-occurring condition (neurological or genetic disorder such as Rett syndrome, tuberous sclerosis, or fragile X), and vision and hearing acuity within normal or corrected normal ranges. Autism diagnoses were confirmed at study entry with the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, Dilavore, & Risi, 1999) and the Autism Diagnostic Interview-Revised (ADI-R; Rutter, LeCouteur & Lord, 2003). Twenty participants met the cut-off for “autism” on both confirmatory measures; two additional subjects met the cut-off for “autism spectrum” on the ADOS.

The chronological age of the 22 participants (all males) at entry ranged from 28 to 42 months. Nineteen of the boys participated in the longitudinal follow-up assessment at ages 40–55 months; the remaining three families were unavailable at follow-up due to health-related issues with the participant or other family members. The mothers of 18 participants (82%) self-identified as White, non-Latino, and the mothers of four participants (18%) self-identified as African-American. In terms of highest level of education completed, 45% of the mothers had a four-year undergraduate or graduate degree, 14% had an associate’s degree, and 41% had a high school diploma or equivalent.

Measures

Communication skills—The four measures listed below were used to derive aggregate scores of each participant’s communication skills at entry and at follow-up in the following categories: Receptive Language, Expressive Language, and Social-Communicative Adaptive Skills. (See *Procedures* for the derivation of aggregate scores.)

The *MacArthur-Bates Communicative Development Inventory-Words and Gestures* form (MCDI-W&G; Fenson et al., 1993) is a standardized parent report tool for assessing an array of communicative skills in children from 8 to 18 months of age, including receptive and expressive vocabulary. Because the participants in this study were chronologically older than the normative sample for the MCDI-W&G, only raw scores were used for analyses. The total number of words understood was one component of the Receptive Language aggregate score, and the total number of words said was one component of the Expressive Language aggregate score.

The *Preschool Language Scale, 4th edition* (PLS-4; Zimmerman et al., 2002) is a standardized observational assessment of the child’s receptive and expressive language from birth through 6 years, 11 months. It is composed of two subscales: Auditory Comprehension and Expressive Communication.

The *Mullen Scales of Early Learning* (MSEL; Mullen, 1995) is a standardized, individually administered assessment that measures the developmental level of children from birth to 68 months. The MSEL includes five domains: Gross Motor, Visual Reception, Fine Motor, Receptive Language, and Expressive Language. An Early Learning Composite (ELC) standard score can be derived that reflects an overall level of functioning across domains, based on a mean of 100 and a standard deviation of 15; the lowest standard score provided is 49.

The *Vineland Adaptive Behavior Scales* (VABS; Sparrow, Balla & Cichetti, 1984) is a standardized, semi-structured survey interview form designed to assess personal and social skills needed for everyday living. The VABS can be used to assess functioning for a large age span (infants to adults) in four major areas: (a) Communication, (b) Daily Living Skills, (c) Socialization, and (d) Motor Skills. In addition to separate scores for the major areas, the VABS yields an overall composite standard score, the Adaptive Behavior Composite, which has a mean of 100 and a standard deviation of 15. The lowest standard score provided is 20. Scores from the Socialization and Communication scales were used to calculate an aggregate measure of Social-Communicative Adaptive Skills. Conceptually, these two areas of adaptive behavior are most closely related to the core deficits in autism, and empirically, they were strongly correlated (r=.80) with one another in this sample.

Responses to nonsocial and CDS stimuli—The nonsocial and CDS stimulus conditions used in this investigation are described in Table 2. These conditions were presented to each participant in the same order. The nonsocial condition, a video of music accompanied by movement of inanimate toys as well as visual patterns, provided a combination of visual and auditory stimuli, and thus was generally comparable in format to the CDS conditions. The nonsocial condition was presented for two minutes, to provide sufficient time to collect RSA data while also keeping the time relatively brief in order to maximize the number of children who would sit through the procedure. The three CDS conditions were developed as a short “battery” of different one-minute samples of CDS with the aim of generating more stable estimates of relative looking and RSA during exposure to CDS that might be obtained from the use of a single CDS sample. The behavioral measure of responses to the stimuli was the proportion of the time the child sustained looking at the target stimuli. Brief glances at the stimuli were not included; rather, sustained looking was coded only when the child looked for at duration of at least two consecutive seconds. Two behavioral variables of responses to the stimuli were calculated: (1) percent of time spent in sustained looking during the nonsocial condition, and (2) percent of time spent in sustained looking during CDS conditions.

The nonsocial and CDS conditions in this study were comparable to conditions used in other studies of young children that have measured resting RSA during passive exposure of children to a video or storybook reading (e.g., Blair & Peters, 2003; Calkins, 1997; Perlman, Camras & Pelphrey, 2008). Physiological responses to the stimuli were indexed by RSA during (1) the nonsocial condition and (2) the CDS conditions. RSA was computed from continuous records of heart activity measured in inter-beat interval (IBI) units (see procedures below). Heart activity was collected using the Mini-Logger 2000 (Mini Mitter Company, Inc., 1994).

Procedures

Participants were recruited from two sources associated with the University of North Carolina at Chapel Hill: (a) the Autism Research Registry coordinated through the Neurodevelopmental Disorders Research Center (NDRC) and (b) the Sensory Experiences Project, funded by the National Institute of Child Health and Human Development. These referral sources distributed recruitment flyers to the parents of potential participants, and received responses from families who were willing to be contacted about the current study. Contact information for interested families was provided to the project staff. Project staff determined that children met preliminary eligibility criteria via a telephone interview (e.g., clinical diagnosis of an ASD, no known genetic anomalies, limited language); then the assessment was scheduled. Parents received a packet by mail that included consent forms, rating scales, demographic and service information, and sample ECG electrodes to use to familiarize the child participant with this aspect of the study procedures. Completed forms and questionnaires were collected when the family came to the research laboratory for the assessments. The project was approved by the Institutional Review Board at the University of North Carolina at Chapel Hill.

Entry assessments were typically conducted across two sessions to maintain the attention and cooperation of the child; all assessments were completed within a 30-day window. Research staff administered the standardized assessments involving direct interaction with the child in a child-friendly assessment room with child-sized furniture. Interviews with parents were completed either at the laboratory or via telephone, depending on the preference of the family.

For the experimental session, two surface electrodes were placed on the child's chest and attached via leads to a small Mini-Logger transmitter unit, which was then placed in the child's pocket or a waist pack. The interbeat intervals of the child's heart beat were detected by the electrodes and transmitted to a Mini-Logger receiver unit located within three feet of the child. A marker switch was connected to the receiver, and a research assistant activated the marker switch to record the beginning and end of each condition during the session.

The child was seated in a high chair positioned 3 feet from the center panel of a puppet theater, which contained a window through which stimuli were presented. The side panels of the puppet theater were covered with black felt and decorated with a few pictures. The child's parent sat in a chair next to the child. All stimulus conditions (see Table 2) were presented within the window. A small, unobtrusive video camera was mounted just above the theater window in order to record the child's behavioral responses, and provided a clear image of the child's face and eyes when he oriented toward the theater window. All experimental sessions were completed between 9 AM and 12 PM to control for the effect of circadian rhythm on heart activity.

Longitudinal follow-up assessments occurred one year after the entry assessments (*M*=11.9 months, range 11 to 14 months) and consisted of repeated measurement of language and social-communicative skills, and documentation of speech-language intervention during the time since the entry assessment. Parents received $25 and the children received a small toy or book for their contributions both for the entry assessments and the follow-up assessments.

Videos of the experimental session were coded using Observer 3.0 software (Software for Behavioral Research, 1996) to measure the child's sustained looking at the stimulus window. The coding of videotapes for sustained looking began once coders reached training reliability standards of at least 80% agreement. Reliability coding was completed on five randomly selected sessions (23%), with a mean interrater agreement of 90% and a mean kappa of .79.

Heart activity was synchronized with the experimental sessions by aligning the markers inserted via the marker switch into the heart activity data with the videotaped data. Heart activity was edited using MxEdit software (Delta Biometrics, Bethesda, MD). RSA was calculated using MxEdit consistent with the procedures developed by Porges (1985). RSA was quantified during each sequential 30-second epoch, and averages were computed for each condition. The mean across the three CDS conditions was used in the data analyses as a measure of RSA during CDS. Heart activity data were dropped for 4 out of the 22 participants from the entry assessment due to technical difficulties in collecting the data (*n*=2) or excessive artifacts (*n*=2). Out of the 19 children seen at the longitudinal follow-up, 15 had heart activity data from the entry assessment and were included in longitudinal analyses.

Data analysis

Three aggregate communication scores were calculated from measures taken at both entry and follow-up assessments, including (1) Receptive Language, comprised of MSEL Receptive Language AE, PLS-4 Auditory Comprehension AE, and MCDI-W&G total words understood; (2) Expressive Language, comprised of MSEL Expressive Language AE, PLS-4 Expressive Communication AE and MCDI-W&G total words said; and (3) Social-Communicative Adaptive Skills, comprised of VABS Socialization AE and VABS Communication AE. In general, aggregate communication scores were derived by calculating the *z*-scores for individual measures (e.g., PLS-4 Auditory Comprehension AE, MSEL Receptive Language AE, MCDI-W&G total words understood), then adding the *z*-scores for the measures included in each aggregate score and determining the mean. In order to anchor all scores to the children's initial performance levels, the means and standard deviations on the measures at the entry assessment were used to calculate the *z*-scores at both entry and follow-up. These aggregate scores will be referred to as "entry scores" and "follow-up scores" in the remainder of this report. For one child, the MCDI at entry was missing and thus the aggregate score for this child was based on his mean *z*-score for the two available measures.

Results

Descriptive Analyses

Communication skills—Descriptive information on the multiple measures of communication used for the aggregate variables of Receptive Language, Expressive Language, and Social-Communicative Adaptive Skills is presented in Table 3. Participants had mean age-equivalent scores around 12 months on standardized tests across the different language and social-communicative measures at entry, with considerable variability around that mean. By follow-up, the participants as a group had mean age equivalent scores around 20 months across measures, with an increase in the range of scores reflecting that some children showed limited to no progress in their scores from entry to follow-up, whereas other children showed considerable progress (see change score data in Table 3).

Behavioral and physiological response to nonsocial and to CDS stimuli—Children engaged in sustained looking 76.3% of the time during presentation of the nonsocial stimuli (*SD* = 20.0), and 53.3% of the time during CDS (*SD* = 28.1). During the presentation of nonsocial stimuli, mean RSA was 4.76, (*SD* = 1.09), and during presentation of CDS stimuli, the mean RSA was 4.33 (*SD* = 1.04).

Primary Analyses

Research question 1: What is the relationship of behavioral and physiological responses during CDS or nonsocial stimuli, to concurrent communication skills in young children with ASD?—Zero order correlations between the behavioral and physiological measures of responses during CDS or nonsocial stimuli, and the child's entry communication skills, are given in Table 4. These data indicate that sustained looking during CDS was significantly associated with entry (concurrent) Receptive Language, Expressive Language, and Social-Communicative Adaptive Skills, with large effect sizes for the magnitude of these correlations. Also, sustained looking during non-social stimuli was significantly correlated with entry Receptive Language and Expressive Language, but not with entry Social- Communicative Adaptive Skills. The magnitude of the correlation of sustained looking during CDS with entry Receptive Language (r[22]=.86) was compared to the magnitude of the correlation of sustained looking during nonsocial stimuli with entry Receptive Language (r[22]=.45) using the Simple Interactive Statistical Analysis (SISA; http://www.quantitativeskills.com/sisa/index.htm) procedure for comparing dependent correlations and confirmed that the former correlation is significantly greater than the latter one (t[19]=2.9, p=.005). For the other two measures (i.e., entry Expressive Language and entry Social-Communicative Adaptive Skills), the same pattern was observed in the relative magnitude of correlations, although the differences were not significant.

RSA during CDS was associated with entry Receptive Language, but not with entry Expressive Language or Social-Communicative Adaptive Skills. RSA during nonsocial stimuli was not associated with any concurrent language or social-communication measures.

Research question 2: Are behavioral or physiological responses during CDS or nonsocial stimuli predictive of communication outcomes in young children with ASD?—We first examined the zero order correlations between the measures of response to CDS and nonsocial stimuli at entry, and communication measures at follow-up (see Table 4). In terms of sustained looking, the percent of looking during CDS at entry was significantly associated with follow-up scores on Receptive Language, Expressive Language, and Social-Communication Adaptive Skills. The association between percent of looking during nonsocial stimuli at entry and the follow-up scores was significant only for Expressive Language, although correlations approached significance for Receptive Language and Social-Communication Adaptive Skills.

Turning to the physiological data, RSA during CDS was significantly correlated with follow-up Expressive Language and Social-Communication Adaptive Skills, and approached significance for Receptive Language. In contrast, RSA during nonsocial stimuli was not significantly correlated with any follow-up scores. Interestingly, the strength of the association between RSA during CDS at entry and follow-up Expressive Language scores increased over the concurrent level of association between these measures at entry (from .27 to .49), as did the strength of the association between RSA during CDS at entry and follow-up Social-Communication Adaptive Skills (from .14 to .63).

Pearson correlations are reported in Table 4. Due to the relatively small sample size, nonparametric Spearman correlations also were calculated, with similar orders of magnitude in the correlations in most cases. The one notable exception was that the correlation between RSA during CDS and Expressive Language at follow-up dropped to a negligible level (r_S=.06) and was not significant.

Next, multiple linear regression analyses were conducted to determine the association between initial measures of response to CDS and follow-up communication scores, after controlling for the corresponding entry communication scores. Given the relatively small sample available for these analyses, we examined Cook's distance scores for each analysis. All Cook's distance scores were less than 1.0, suggesting that no individual participant unduly influenced the results of the multiple regression analyses (Chatterjee, Hadi and Price, 2000).

The results of the multiple regression analyses using sustained looking during CDS as a predictor of follow-up communication scores are shown in Table 5. Although sustained looking during CDS had a strong zero-order correlation with each of the follow-up scores (as shown in Table 4), it failed to account for significant additional variance in any of the three follow-up scores after controlling for the corresponding entry score.

A second set of regression analyses examined the extent to which RSA during CDS predicted communication scores at follow-up. As seen in Table 6, RSA during CDS did not account for significant additional variance in Receptive Language at follow-up after controlling for entry Receptive Language, but did account for significant additional variance in follow-up Expressive Language as well as in follow-up Social-Communication Adaptive Skills.

Discussion

As hypothesized, sustained looking during CDS was significantly related to concurrent measures of Receptive Language, Expressive Language, and Social-Communicative Adaptive Skills. These findings are consistent with the results of Kuhl et al. (2005) and Paul et al. (2007), who also found significant levels of association between attention to CDS and concurrent measures of language performance. Contrary to our hypothesis, sustained looking during nonsocial stimuli was also significantly related to concurrent measures of Receptive Language and Expressive Language, suggesting that some general attention factors may influence the development of language among young children with ASD, or the performance of these children on standardized measures of language, or both. Nevertheless, the correlation between sustained looking during CDS and Receptive Language was significantly stronger than the correlation between sustained looking during nonsocial stimuli and Receptive Language, with similar, although nonsignificant, trends for the Expressive Language and Social-Communicative Adaptive Skills. Thus, in addition to general attention factors, the specific ability to sustain attention during CDS appears either to aid language development or to be aided by concurrent language skills, or both.

Longitudinally, the pattern of results for sustained looking was parallel to the concurrent correlations, with moderate to strong zero order correlations between looking during CDS and the outcome measures and moderately low zero order correlations between looking during nonsocial stimuli and the outcome measures. The moderate to strong associations of looking during CDS with follow-up language and social-communication aggregate scores also are consistent with the results reported by Paul et al. (2007), who found that the length of attention to CDS of two-year-olds with ASD was positively correlated with receptive language one year later. Our regression analyses demonstrated, however, that sustained looking during CDS at an earlier time point did not predict communication outcomes one year later after partialing out the child’s entry communication performance. Thus, the direction of effects in this instance is unclear. Children who had developed higher levels of language or social-communicative skills at the time of entry into this study may have been able to sustain more attention to CDS at that point because they understood more of what was being said. Alternatively, perhaps these children had been more motivated to attend to CDS during the infancy period, and therefore had developed stronger language and social-communicative skills by two to three years of age when they entered the study. A third possibility, and perhaps most likely, is that both factors operated in a tightly integrated, reciprocal fashion and influenced the children’s initial and subsequent learning and attention skills.

With regard to our physiological variable, RSA during CDS was associated only with entry Receptive Language, and not with entry Expressive Language or entry Social-Communication Adaptive Skills. Although previous research has found that RSA is concurrently related to measures of social behaviors (e.g., Blair & Peters, 2003; Calkins, 1997; Heilman, Bal, Bazhenova, & Porges, 2007; Porges et al., 1994), there were marked differences in the sample, experimental protocol, and outcome measures used in the present study compared to previous research. Thus, the findings of this study do not directly challenge those of the prior research on the concurrent association between RSA and developmental measures, but add to the available information.

The current study makes unique contributions to the literature in its findings related to the predictive associations of RSA with later communication skills in children with ASD. Linear regression analyses that controlled for entry communication scores indicated that RSA during CDS predicted follow-up Expressive Language and Social Communication Adaptive Skills. Although not definitive, the pattern of results suggests that the physiological regulation of attention to CDS influences the ongoing development of communication skills, rather than communication skills having a deterministic influence on physiological responses during CDS. Further, the association of RSA during CDS, but not during nonsocial stimuli, with later communication outcomes, suggests that children with ASD make variable physiological adjustments during the CDS conditions that are important in their processing of language and other communication stimuli. If, as proposed by the Polyvagal Theory (Porges, 1995), the RSA of these children with ASD reflects influences of the neocortex on a complex social engagement system that includes the vagus, then children who respond with higher RSA during CDS are possibly those who are experiencing stronger social affiliation and, relatedly, a more optimal physiological response for processing and learning from CDS.

We are uncertain about how to explain the lack of a predictive association between RSA during CDS at entry and follow-up Receptive Language, especially in light of the concurrent association between these measures at entry. One possible explanation is that there is variability in the way RSA influences communication in young children with ASD over time. Specifically, RSA may have a more direct impact on receptive language early in a child’s language development, but over time this association may be mediated by other influences, such as parental interaction style, as suggested in a recent study of children with varying birth conditions by Feldman & Eidelman (2009).

Limitations

The current study is limited in several respects. First, the sample size is small for the regression analyses used. Due to the limited power, we ran a series of regression analyses with two variables each, rather than testing all variables of interest in a single model. Additionally, we attempted to address the sample size limitation by examining the possible influence of outliers on the regression analyses. The low Spearman *rho* correlation between RSA during CDS and follow-up Expressive Language, contrasted with a moderately strong and significant Pearson *r* correlation emphasizes the importance of replicating these results with a larger sample. We chose not to adjust the alpha levels for multiple tests of significance, preferring in this initial study to accept the risk of Type I errors over Type II errors. Thus, the likelihood of false positive findings is increased, and replication of our results in future studies is an important goal. The small sample size also increases the possibility of false negative findings due to a lack of power to detect significant relations, and replication with a larger sample might provide some additional clarification in this regard as well.

A second challenge to unambiguous interpretation of our results is the nature of the stimuli presented (see Table 2). One goal of the current investigation was to expose the children to nonsocial and social stimuli with high ecological validity. Thus, our nonsocial and social stimuli were complex, multimodal stimuli involving both visual and auditory components; further, one of the CDS stimulus conditions was presented live by a research assistant, whereas all other conditions were presented via videotape. As a result, our stimuli do not represent carefully controlled analogs of speech versus nonspeech stimuli, or child-directed speech versus adult-directed speech stimuli. Possibly some of our findings may be attributable to uncontrolled factors, such as a greater degree of visual movement in the nonspeech stimuli, or the effects of including a live condition among our CDS stimuli but not in the nonsocial stimuli.

A third limitation of this study is that our participants were quite impaired relative to age expectations, and in the lower range of functioning even among young children with ASD. As a result, the findings in this study may not generalize to young children with ASD who are functioning at higher language and cognitive levels.

Summary and Future Directions

To our knowledge, this study is the first investigation to combine behavioral and physiological measures of response to CDS among children with ASD, and the first longitudinal investigation of concurrent and predictive relations between RSA and later language and social-communicative outcomes in this population. As such, replicating the results with a larger sample of young children with ASD is a future goal of our research program. In addition, a larger sample would permit testing of more complex regression models, such as evaluating in a single model the relative and unique contributions of behavioral and physiological measures of attention to CDS in predicting communication outcomes.

Given the emergent nature of the current study, drawing clinical implications is a highly speculative endeavor. One possibility is that measures of RSA in young children with ASD during exposure to CDS or during social interactions may predict variable response to treatment. Hypothetically, if children with higher RSA in social contexts have stronger social affiliation with other people, then a relationship-based intervention approach (Odom, Boyd, Hall & Hume, in press) may be more effective for those children, whereas for children with relatively low RSA during social contexts, an applied behavior approach that initially reinforces new communication skills with nonsocial reinforcers may be more effective. Another possibility is that children with ASD might benefit from interventions to stimulate the vagus. For instance, researchers have reported improvements in baseline RSA for high-risk infants who receive infant massage (Diego, Field & Hernandez-Reif, 2005), and have suggested that vagal nerve stimulation might improve behavioral adaptation for children with ASD (Escalona, Field, Singer-Strunck, Cullen & Hartshorn, 2001). Possibly, early interventions for children with ASD that result in greater improvements in parasympathetic regulation would be associated with the strongest long term social-communication outcomes, independent of immediate improvements in communication skills resulting from the intervention.

In a review of the literature on vagal activity and infant development, Field and Diego (2008) pointed out that in multivariate studies, RSA is found to be one of multiple variables that mediate development. In addition, these authors noted that the correlational designs of most studies examining vagal activity in child development do not allow conclusions that vagal activity plays a causal role. With attention to the important points raised by Field and Diego, future research can build on the methods and novel findings of this study to achieve a better understanding of complex developmental processes affecting language and communication outcomes in children with ASD.

Acknowledgments

The authors gratefully acknowledge the support of the National Alliance for Autism Research/Autism Speaks 681 and the National Institute for Child Health and Human Development R01-HD42168; the families who participated in the study; the assistance of Doanne L. Ward-Williams, Kerry Callahan Mandulak, Megan McLester, Renee Clark, Beth Schultz, Irene Chan, and Sheila Lang in recruitment, data collection, and coding; and Elizabeth R. Crais, who provided a valuable critique of the manuscript.

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Table 1

Participant characteristics (*N* = 22)

	M	*SD*	Range
Chronological Age[a]	35.0	4.28	28–42
PLS-4 Language Age [a, b]	11.68	6.43	3–22
PLS-4 Standard Score	54.32	7.51	50–76
MSEL ELC[c]	51.09	3.79	49–63
VABS ABC [d]	57.82	6.95	49–74

[a] in months

[b] Preschool Language Scale-4

[c] Mullen Scales of Early Learning Early Learning Composite

[d] Vineland Adaptive Behavior Scales Adaptive Behavior Composite

Table 2

Experimental Session of Nonsocial Stimuli and Child-Directed Speech (CDS)

Stimulus	Duration	Type	Description of stimulus
Baby Bach Video	2 minutes	Non-social	Children's music video with no social stimuli
Name Call	1 minute	Social	Up to 5 name call trials while Baby Bach video continued to play (Data not analyzed for the current study)
Video Story	1 minute	Social	Video of a female actor reading out of a novel storybook, as if reading to the child (book facing outward, actor directly facing camera)
Puppet Show	1 minute	Social	Live puppet show performed by female examiner
Nonsense Toy	1 minute	Social	Video of a female actor playing with and describing a novel toy using nonsense words

Table 3

Entry and Follow-up Language & Social-Communication Developmental Assessment Results

	Entry			Follow-Up			Change Scores		
Measure	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**range**
PLS-4 AC[a]	10.9	7.8	1–23	20.3	11.9	5–42	9.0	6.8	−3—24
PLS-4 EC [b]	13.1	6.1	5–27	20.6	10.3	8–43	7.4	7.0	−2—24
MSEL RL[c]	12.7	8.3	1–27	21.2	12.4	4–57	8.4	6.8	−1—30
MSEL EL[d]	12.0	6.9	2–26	19.4	13.9	5–60	7.4	11.2	−6—46
MCDI #WU[e]	162.3	120.8	2–352	228.2	127.9	8–394	65.9	67.6	−27—244
MCDI #WS[f]	69.4	102.7	0–340	136.7	153.1	0–384	67.3	93.2	−4—337
VABS Comm[g]	12.1	6.3	3–23	17.7	9.4	4–34	4.6	5.3	−3—18
VABS Social[h]	12.0	3.9	4–18	18.3	9.2	6–42	6.3	7.7	−4—24

[a] Preschool Language Scale-4 Auditory Comprehension age equivalent

[b] Preschool Language Scale-4 Expressive Communication age equivalent

[c] Mullen Scales of Early Learning Receptive Language age equivalent

[d] Mullen Scales of Early Learning Expressive Language age equivalent

[e] MacArthur Communicative Development Inventories total words understood

[f] MacArthur Communicative Development Inventories total words said

[g] Vineland Adaptive Behavior Scales Communication age equivalent

[h] Vineland Adaptive Behavior Scales Socialization age equivalent

Table 4

Correlations between Entry Measures of Response to Nonsocial and CDS Stimuli, and Language and Social Communication Skills at Entry and Follow-up

		RL-1[b]	**EL-1**[c]	**SC-1**[d]	**RL-2**[e]	**EL-2**[f]	**SC-2**[g]
% Looking-Nonsocial[a]	*r*	.452	.544	.276	.380	.396	.320
	p	.017	.004	.107	.054	.047	.091
	N	22	22	22	19	19	19
% Looking-CDS[a]	*r*	.859	.756	.613	.787	.715	.585
	p	.000	.000	.001	.000	.000	.004
	N	22	22	22	19	19	19
RSA-Nonsocial[a]	*r*	.203	.272	−.077	.058	.186	.188
	p	.210	.138	.381	.419	.253	.251
	N	18	18	18	15	15	15
RSA-CDS[a]	*r*	.427	.274	.139	.395	.496	.632
	p	.039	.136	.291	.073	.030	.006
	N	18	18	18	15	15	15

[a] one-tailed tests

[b] Receptive Language aggregate score at entry

[c] Expressive Language aggregate score at entry

[d] Social-Communicative Adaptive Skills aggregate score at entry

[e] Receptive Language aggregate score at follow-up

[f] Expressive Language aggregate score at follow-up

[g] Social-Communicative Adaptive Skills aggregate score at follow-up

Table 5

Summary of Hierarchical Regression Analyses for Sustained Looking during CDS as a Predictor of Communication Scores at Follow-up

Variable	***B***	***SE B***	***β***	***R*²**
Predicting RL-2 (*N*=19)				
Step 1				
RL-1	1.16	.14	.89***	.79
Step 2				
RL-1	1.11	.30	.86**	
Sustained looking-CDS	.19	1.10	.04	.79
Predicting EL-2 (*N*=19)				
Step 1				
EL-1	1.46	.27	.80***	.64
Step 2				
EL-1	1.08	.38	.59*	
Sustained looking-CDS	1.76	1.32	.28	.67
Predicting SC-2 (*N*=19)				
Step 1				
SC-1	1.43	.31	.74***	.55
Step 2				
SC-1	1.28	.46	.66*	
Sustained looking-CDS	.76	1.65	.11	.56

RL-2 Receptive Language aggregate score at follow-up

RL-1 Receptive Language aggregate score at entry

EL-2 Expressive Language aggregate score at follow-up

EL-1 Expressive Language aggregate score at entry

SC-2 Social-Communicative Adaptive Skills aggregate score at follow-up

SC-1 Social Communicative Adaptive Skills aggregate score at entry

[*] p<.05

[**] p<.01

[***] p<.001

Table 6

Summary of Hierarchical Regression Analyses for RSA during CDS as a Predictor of Communication Scores at Follow-up

Variable	***B***	***SE B***	***β***	***R***^{2}
Predicting RL-2 (*N*=15)				
Step 1				
RL-1	1.30	.14	.94***	.87
Step 2				
RL-1	1.27	.15	.91***	
Vagal tone-CDS	.11	.17	.07	.88
Predicting EL-2 (*N*=15)				
Step 1				
EL-1	1.42	.31	.79***	.62
Step 2				
EL-1	1.31	.26	.73***	
Vagal tone-CDS	.73	.29	.37*	.75
Predicting SC-2 (*N*=15)				
Step 1				
SC-1	1.35	.31	.77**	.59
Step 2				
SC-1	1.12	.25	.64**	
Vagal tone-CDS	.92	.30	.45**	.77

RL-2 Receptive Language aggregate score at follow-up

RL-1 Receptive Language aggregate score at entry

EL-2 Expressive Language aggregate score at follow-up

EL-1 Expressive Language aggregate score at entry

SC-2 Social-Communicative Adaptive Skills aggregate score at follow-up

SC-1 Social Communicative Adaptive Skills aggregate score at entry

* $p<.05$

** $p<.01$

*** $p<.001$