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

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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: 35 months) participated in a longitudinal study. At entry, behavioral (i.e., percentage looking) and physiological (i.e., vagal activity) measures were collected during the presentation of CDS stimuli. A battery of standardized communication measures was administered at entry and readministered 12 months later.

Results: Percentage 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, 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 percentage 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. Furthermore, higher vagal activity during CDS predicts better communication outcomes 12 months later, after initial communication skills are accounted for. Further research is needed to better understand the physiological mechanisms underlying variable responses to CDS among children with ASD.

KEY WORDS: autism spectrum disorders, preschool children, attention, outcomes

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 because of 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.
One striking, replicated finding related to the pre-linguistic 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, Coffey-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 article 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 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 indexes of attention quality, and the vagal system in children with ASD.

**CDS**

CDS is characterized by many differences when compared with 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 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 1 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 with 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, 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 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 tendency of children with ASD not to respond reliably or promptly to a 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 fact that children with ASD do not orient quickly and reliably may result in less time spent attending to CDS over time. Even if a child with an ASD initially orients to CDS, a limited maintenance of attention likely would prevent that 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). In this investigation we examined 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 conducted by Kuhl et al. (2005), a subgroup of children 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 et al. (2007) did not partial out the association between receptive language at age 2 and receptive language at...
age 3, 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, like all behaviors, have underlying physiological bases that 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–digest) than the sympathetic (i.e., fight–flight) system (Richards & Casey, 1991). The influences of the parasympathetic system on the heart are often 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) presumably reflects 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 a 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, a 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 with greater behavioral, attentional, and emotional responsiveness. Thus, high levels of infant responsiveness can be evidenced in more extreme negative and positive emotional reactions but lead 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 Beauchaine, Neuhaus, Brenner, and Gatzke-Kopp (2008) discussed, greater vagal influences on the heart also appear to protect children from developing psychopathologies associated with varying environmental risk factors. In general, then, a 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’s (1995b) 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 two different branches of the vagus, that is, (a) the myelinated and phylogenetically more recent ventral vagal complex and (b) the unmyelinated and phylogenetically older dorsal vagal complex. Porges (2007) argued that the ventral vagal complex is linked to behavioral functions of social communication, self-soothing, and calming. He further argued 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 the 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 the heart rate as the individual reacts with a fight–flight response. A number of studies support Porges’s (1995b) 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 (Birnstein & 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 et al., 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 with control children (Ming, Julu, Brimacombe, Connor, & Daniels, 2005), as well as diminished vagal adaptation to tasks with cognitive demands (Althaus et al., 2004; Toichi & Kamio,
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 in their amount of looking at videos of a baby crying versus a baby playing happily, and they did not differ in heart rate in response to the two videos; however, these investigators did not measure 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 This Study**

The overarching focus of this study was 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; that is, the special features of CDS are assumed to arise in part from adults’ efforts to establish positive affective relations with a young child. Furthermore, we included a contrasting non-social 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:

**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?**

We formulated the following two hypotheses:

**Hypothesis 1a.** Amount of looking during CDS stimuli (but not during nonsocial stimuli) will be positively correlated with concurrent measures of communication skills.

**Hypothesis 1b.** Vagal tone during CDS stimuli (but not during nonsocial stimuli) will be positively correlated with concurrent measures of communication skills.

Our rationales for the hypotheses were as follows. First, 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. Second, both the nonsocial and CDS conditions in this study were designed to be nonstressful and nondemanding. 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 (cf. Beauchaine et al., 2008). 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.

**Research Question 2: Are behavioral or physiological responses during CDS or nonsocial stimuli predictive of communication outcomes in young children with ASD 1 year later, after controlling for initial communication skills?**

We formulated the following two hypotheses:

**Hypothesis 2a.** Looking during CDS stimuli (but not during nonsocial stimuli) will account for a significant amount of variance in communication outcomes 1 year later, with a greater amount of looking during CDS predicting better communication outcomes.

**Hypothesis 2b.** RSA during CDS stimuli (but not during nonsocial stimuli) will account for a significant amount of variance in communication outcomes 1 year later, with higher RSA during CDS predicting better communication outcomes.

Our rationale was the following: 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 (AE), 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 by means of looking) and quality of attention to CDS (measured physiologically by means of RSA) would each have a positive association with outcomes 1 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 AE of less than 24 months at entry, absence of a co-occurring condition (neurological or genetic disorder,
Table 1. Participant characteristics.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>M (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronological age (months)</td>
<td>35.0 (4.28)</td>
<td>28–42</td>
</tr>
<tr>
<td>PLS-4 language age (months)</td>
<td>11.68 (6.43)</td>
<td>3–22</td>
</tr>
<tr>
<td>PLS-4 standard score</td>
<td>54.32 (7.51)</td>
<td>50–76</td>
</tr>
<tr>
<td>MSEL ELC</td>
<td>51.09 (3.79)</td>
<td>49–63</td>
</tr>
<tr>
<td>VABS ABC</td>
<td>57.82 (6.95)</td>
<td>49–74</td>
</tr>
</tbody>
</table>


e.g., 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 (Lord, Rutter, DiLavore, & Risi, 1999) and the Autism Diagnostic Interview—Revised (Rutter, LeCouteur, & Lord, 2003). Twenty participants met the cutoff for autism on both confirmatory measures; 2 additional subjects met the cutoff for autism spectrum on the Autism Diagnostic Observation Schedule.

The chronological age of the 22 participants (all boys) at entry ranged from 28 to 42 months. Nineteen of the boys participated in the longitudinal follow-up assessment at ages 40 through 55 months; the remaining three families were unavailable at follow-up because of health-related issues with the participant or other family members. The mothers of 18 participants (82%) self-identified as European American, non-Latino, and the mothers of 4 participants (18%) self-identified as African American. In terms of highest level of education completed, 45% of the mothers had a 4-year undergraduate or graduate degree, 14% had an associate’s degree, and 41% had a high school diploma or equivalent.

Measures

Communication skills. We used the four measures listed next to derive aggregate scores of each participant’s communication skills at entry and at follow-up in the following three categories: (a) receptive language, (b) expressive language, and (c) social-communicative adaptive skills. (See the Procedure section for the derivation of aggregate scores.)

The MacArthur–Bates Communicative Development Inventory, Words and Gestures form (CDI:WG; 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 CDI:WG, we used only raw scores 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, Fourth Edition (PLS-4; Zimmerman, Steiner, & Pond, 2002), is a standardized observational assessment of a child’s receptive and expressive language from birth through 6 years, 11 months. It is composed of two subscales: (a) Auditory Comprehension and (b) 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: (a) Gross Motor, (b) Visual Reception, (c) Fine Motor, (d) Receptive Language, and (e) Expressive Language. An Early Learning Composite 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, & Cicchetti, 1984) is a standardized, semistructured 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. We used scores from the Socialization and Communication scales to calculate an aggregate measure of social-communicative adaptive skills. These two areas of adaptive behavior are conceptually 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 2 min, to provide sufficient time to collect RSA data while also keeping the time relatively brief to maximize the number of children who would sit through the procedure. The three CDS conditions were developed as a short battery of different 1-min samples of CDS with the aim of generating more stable estimates of relative looking and RSA during exposure to CDS than 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; instead, sustained looking was coded only when the child looked for a duration of at least 2 consecutive seconds. We calculated two behavioral variables of responses to the stimuli: (a) percentage of time spent in sustained looking during the nonsocial condition and (b) percentage 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 both the nonsocial condition and the CDS conditions. RSA was computed from continuous records of heart activity measured in interbeat interval units (see Procedure section). Heart activity was collected using the Mini-Logger 2000 (Mini Mitter Company, Inc.).

**Procedure**

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, 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 this study. Contact information for interested families was provided to the project staff. Project staff determined that children met preliminary eligibility criteria by means of a telephone interview (e.g., clinical diagnosis of an ASD, no known genetic anomalies, limited language), and then the assessment was scheduled. Parents received a packet by mail that included consent forms, rating scales, demographic and service information, and sample electroencephalography 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 over the 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 3 ft 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 ft 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 it provided a clear image of

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Duration (min)</th>
<th>Type</th>
<th>Description of stimulus</th>
</tr>
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<tbody>
<tr>
<td>Baby Bach video</td>
<td>2</td>
<td>Nonsocial</td>
<td>Children’s music video with no social stimuli</td>
</tr>
<tr>
<td>Name call</td>
<td>1</td>
<td>Social</td>
<td>Up to 5 name call trials while Baby Bach video continued to play(^a)</td>
</tr>
<tr>
<td>Video story</td>
<td>1</td>
<td>Social</td>
<td>Video of a female actor reading out of a novel storybook, as if reading to the child (book facing outward, actor directly facing camera)</td>
</tr>
<tr>
<td>Puppet show</td>
<td>1</td>
<td>Social</td>
<td>Live puppet show performed by female examiner</td>
</tr>
<tr>
<td>Nonsense toy</td>
<td>1</td>
<td>Social</td>
<td>Video of a female actor playing with and describing a novel toy using nonsense words</td>
</tr>
</tbody>
</table>

\(^a\)Data not analyzed for this study.
the child's face and eyes when he oriented toward the theater window. All experimental sessions were completed between 9:00 a.m. and 12:00 p.m. to control for the effect of circadian rhythm on heart activity.

Longitudinal follow-up assessments were conducted 1 year after the entry assessments ($M = 11.9$ months, range: 11–14 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.

We coded videos of the experimental session 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.

We synchronized heart activity with the experimental sessions by aligning the markers inserted via the marker switch into the heart activity data with the videotaped data. We edited heart activity data using MxEdit software (Delta Biometrics of Bethesda, MD; patented by Porges, 1985). We calculated RSA using MxEdit in a manner consistent with the procedures developed by Porges (1985). We quantified RSA during each sequential 30-s epoch and computed averages for each condition. We used the mean across the three CDS conditions in the data analyses as a measure of RSA during CDS. We dropped heart activity data for 4 of the 22 participants from the entry assessment because of 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**

We calculated three aggregate communication scores from measures taken at both entry and follow-up assessments, including (a) receptive language, which comprised MSEL Receptive Language AE, PL-S-4 Auditory Comprehension AE, and CDI:WG total words understood; (b) expressive language, which comprised MSEL Expressive Language AE, PL-S-4 Expressive Communication AE, and CDI:WG total words said; and (c) social-communicative adaptive skills, which comprised VABS Socialization AE and VABS Communication AE. In general, we derived aggregate communication scores by calculating the $z$ scores for individual measures (e.g., PL-S-4 Auditory Comprehension AE, MSEL Receptive Language AE, CDI:WG total words understood), then adding the $z$ scores for the measures included in each aggregate score and determining the mean. To anchor all scores to the children’s initial performance levels, we used the means and standard deviations on the measures at the entry assessment to calculate the $z$ scores at both entry and follow-up. We refer to these aggregate scores as *entry scores* and *follow-up scores* in the remainder of this article. For 1 child, the CDI:WG 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 AE 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 AE 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, the mean RSA was 4.76 ($SD = 1.09$), and during presentation of CDS stimuli the mean RSA was 4.33 ($SD = 1.04$). An explanation of the RSA index can be found in Porges (1995a).

**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 children’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 nonsocial stimuli was significantly correlated with entry receptive language and expressive language, but not with...
entry social-communicative adaptive skills. We compared the magnitude of the correlation of sustained looking during CDS with entry receptive language, $r(22) = .86$, with the magnitude of the correlation of sustained looking during nonsocial stimuli with entry receptive language, $r(22) = .45$, using the Simple Statistical Interactive Analysis (http://www.quantitativeskills.com/sisa/index.htm) procedure for comparing dependent correlations and confirmed that the former correlation is significantly greater than the latter, $t(19) = 2.9, p = .005$. We observed the same pattern for the other two measures (i.e., entry expressive language and entry social-communicative adaptive skills), 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 percentage of looking during CDS at entry was significantly associated with follow-up scores on receptive language, expressive

### Table 3. Entry and follow-up language and social-communication developmental assessment results.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Entry</th>
<th>Follow-up</th>
<th>Change scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$Range$</td>
</tr>
<tr>
<td>PLS-4 AC</td>
<td>10.9</td>
<td>7.8</td>
<td>1–23</td>
</tr>
<tr>
<td>PLS-4 EC</td>
<td>13.1</td>
<td>6.1</td>
<td>5–27</td>
</tr>
<tr>
<td>MSEL RL</td>
<td>12.7</td>
<td>8.3</td>
<td>1–27</td>
</tr>
<tr>
<td>MSEL EL</td>
<td>12.0</td>
<td>6.9</td>
<td>2–26</td>
</tr>
<tr>
<td>CDI WU</td>
<td>162.3</td>
<td>120.8</td>
<td>2–352</td>
</tr>
<tr>
<td>CDI WS</td>
<td>69.4</td>
<td>102.7</td>
<td>0–340</td>
</tr>
<tr>
<td>VABS Comm</td>
<td>12.1</td>
<td>6.3</td>
<td>3–23</td>
</tr>
<tr>
<td>VABS Social</td>
<td>12.0</td>
<td>3.9</td>
<td>4–18</td>
</tr>
</tbody>
</table>

**Note.** PLS-4 AC = Preschool Language Scale—4th Edition, Auditory Comprehension age equivalent; PLS-4 EC = PLS-4 Expressive Communication age equivalent; MSEL RL = Mullen Scales of Early Learning Receptive Language age equivalent; MSEL EL = MSEL Expressive Language age equivalent; CDI WU = MacArthur Communicative Development Inventories total words understood; CDI WS = CDI total words said; VABS Comm = Vineland Adaptive Behavior Scales Communication age equivalent; VABS Social = VABS 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.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistic</th>
<th>RL-1</th>
<th>EL-1</th>
<th>SC-1</th>
<th>RL-2</th>
<th>EL-2</th>
<th>SC-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Looking–nonsocial</td>
<td>$r$=.452</td>
<td>.544</td>
<td>.276</td>
<td>.380</td>
<td>.396</td>
<td>.320</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$p=.017$</td>
<td>.004</td>
<td>.107</td>
<td>.054</td>
<td>.047</td>
<td>.091</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N=22$</td>
<td>22</td>
<td>22</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>% Looking–CDS</td>
<td>$r=.859$</td>
<td>.756</td>
<td>.613</td>
<td>.787</td>
<td>.715</td>
<td>.585</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$p=.000$</td>
<td>.000</td>
<td>.001</td>
<td>.000</td>
<td>.000</td>
<td>.004</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N=22$</td>
<td>22</td>
<td>22</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>RSA–nonsocial</td>
<td>$r=.203$</td>
<td>.272</td>
<td>−.077</td>
<td>.058</td>
<td>.186</td>
<td>.188</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N=18$</td>
<td>18</td>
<td>18</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>RSA–CDS</td>
<td>$r=.427$</td>
<td>.274</td>
<td>.139</td>
<td>.395</td>
<td>.496</td>
<td>.632</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$p=.039$</td>
<td>.136</td>
<td>.291</td>
<td>.073</td>
<td>.030</td>
<td>.006</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N=18$</td>
<td>18</td>
<td>18</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

**Note.** All tests are one-tailed. RL-1 = receptive language aggregate score at study entry; EL-1 = expressive language aggregate score at study entry; SC-1 = social-communicative adaptive skills aggregate score at study entry; RL-2 = receptive language aggregate score at follow-up; EL-2 = expressive language aggregate score at follow-up; SC-2 = social-communicative adaptive skills aggregate score at follow-up.
language, and social-communication adaptive skills. The association between percentage of looking during non-social 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 it approached significance for receptive language. In contrast, RSA during nonsocial stimuli was not significantly correlated with any follow-up scores. It is interesting that 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 product–moment correlations are reported in Table 4. Because of the relatively small sample size, we also calculated nonparametric Spearman correlations, 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, we conducted multiple linear regression analyses 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, & 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.

With a second set of regression analyses we 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 it did account for significant additional variance in follow-up expressive language as well as in follow-up social-communication adaptive skills.

**Table 5. Summary of hierarchical regression analyses for sustained looking during CDS as a predictor of communication scores at follow-up.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicting RL-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1: RL-1</td>
<td>1.16</td>
<td>0.14</td>
<td>.89***</td>
<td>.79</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL-1</td>
<td>1.11</td>
<td>0.30</td>
<td>.86**</td>
<td>.79</td>
</tr>
<tr>
<td>Sustained looking–CDS</td>
<td>.19</td>
<td>1.10</td>
<td>.04</td>
<td>.79</td>
</tr>
<tr>
<td>Predicting EL-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1: EL-1</td>
<td>1.46</td>
<td>0.27</td>
<td>.80***</td>
<td>.64</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EL-1</td>
<td>1.08</td>
<td>0.38</td>
<td>.59*</td>
<td>.64</td>
</tr>
<tr>
<td>Sustained looking–CDS</td>
<td>1.76</td>
<td>1.32</td>
<td>.28</td>
<td>.67</td>
</tr>
<tr>
<td>Predicting SC-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1: SC-1</td>
<td>1.43</td>
<td>0.31</td>
<td>.74***</td>
<td>.55</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC-1</td>
<td>1.28</td>
<td>0.46</td>
<td>.66*</td>
<td>.56</td>
</tr>
<tr>
<td>Sustained looking–CDS</td>
<td>0.76</td>
<td>1.65</td>
<td>.11</td>
<td>.56</td>
</tr>
</tbody>
</table>

Note. $N = 19$.

*p < .05. **p < .01. ***p < .001.

**Table 6. Summary of hierarchical regression analyses for vagal tone during CDS as a predictor of communication scores at follow-up.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicting RL-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1: RL-1</td>
<td>1.30</td>
<td>0.14</td>
<td>.94***</td>
<td>.87</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RL-1</td>
<td>1.27</td>
<td>0.15</td>
<td>.91***</td>
<td>.88</td>
</tr>
<tr>
<td>Vagal tone–CDS</td>
<td>0.11</td>
<td>0.17</td>
<td>.07</td>
<td>.88</td>
</tr>
<tr>
<td>Predicting EL-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1: EL-1</td>
<td>1.42</td>
<td>0.31</td>
<td>.79***</td>
<td>.62</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EL-1</td>
<td>1.31</td>
<td>0.26</td>
<td>.73***</td>
<td>.75</td>
</tr>
<tr>
<td>Vagal tone–CDS</td>
<td>0.73</td>
<td>0.29</td>
<td>.37*</td>
<td>.75</td>
</tr>
<tr>
<td>Predicting SC-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1: SC-1</td>
<td>1.35</td>
<td>0.31</td>
<td>.77**</td>
<td>.59</td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SC-1</td>
<td>1.12</td>
<td>0.25</td>
<td>.64**</td>
<td>.77</td>
</tr>
<tr>
<td>Vagal tone–CDS</td>
<td>0.92</td>
<td>0.30</td>
<td>.45**</td>
<td>.77</td>
</tr>
</tbody>
</table>

Note. $N = 15$.

*p < .05. **p < .01. ***p < .001.

**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 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 2-year-olds with ASD was positively correlated with receptive language 1 year later. Our regression analyses demonstrated, however, that sustained looking during CDS at an earlier time point did not predict communication outcomes 1 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 2 to 3 years of age, when they entered the study. A third, and perhaps most likely, possibility 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-communicative 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 this study compared with previous research. Thus, our findings do not directly challenge those of the prior research on the concurrent association between RSA and developmental measures, but they add to the available information.

This 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. Furthermore, 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, 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 conducted by Feldman and Eidelman (2009).

**Limitations**

This study is limited in several respects. First, the sample size is small for the regression analyses used. Because of the limited power, we conducted a series of regression analyses with two variables each, rather than testing all variables of interest in a single model. We
also 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 product–moment 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 this 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; furthermore, one of the CDS stimulus conditions was presented live by a research assistant, whereas all other conditions were presented by means of videotape. As a result, our stimuli do not represent carefully controlled analogs of speech versus nonspeech stimuli or CDS versus adult-directed speech stimuli. It is possible that 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 present findings 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. Therefore, 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 this 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, 2010) 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). It is possible that 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 has been found to be one of multiple variables that mediate development. They also noted that the correlational designs of most studies that have examined vagal activity in child development have not allowed conclusions that vagal activity plays a causal role. With attention to the important points Field and Diego raised, future research can build on the methods and novel findings of this study to achieve a better understanding of the complex developmental processes that affect language and communication outcomes in children with ASD.

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