Respiratory Sinus Arrhythmia: A Marker for Positive Social Functioning and Receptive Language Skills in Children with Autism Spectrum Disorders

ABSTRACT: The current study builds on the emerging autism spectrum disorder (ASD) literature that associates autonomic nervous system activity with social function, and examines the link between respiratory sinus arrhythmia (RSA) and both social behavior and cognitive function. The RSA response pattern was assessed in 23 4- to 7-year-old children diagnosed with an ASD. Higher baseline RSA amplitudes were associated with better social behavior (i.e., more conventional gestures, more instances of joint attention) and receptive language abilities. Similar to reports of typically developing children, ASD children with higher RSA amplitude at baseline showed greater RSA and HP reactivity during an attention-demanding task. These results highlight the importance of studying RSA as a marker of positive function in children with ASD.

Cardiovascular activity has been measured in children and adolescents with autism spectrum disorders (ASDs) over the last four decades (e.g., MacCulloch & Williams, 1971). Only recently, however, has the measurement of respiratory sinus arrhythmia (RSA) provided theoretical and empirical insight to the neurophysiological mechanisms that may contribute to behavioral challenges in ASD. The current study builds on preliminary evidence relating RSA to social functioning in children with ASD, and adds to this literature by linking RSA to receptive language ability. In addition, the utility of RSA as a marker of neurophysiological function was examined during an attention-demanding task. This perspective highlights RSA as a global measure of functioning in ASD.

SOCIAL ENGAGEMENT AND RSA: THE THEORETICAL LINK

The Polyvagal Theory provides a conceptual framework for understanding the link between neurophysiological functioning and both effective social behavior and receptive language skills (Porges, 1995, 1998, 2001, 2003b, 2007b, 2009; Porges & Lewis, 2009). Polyvagal Theory describes a social communication circuit comprised of autonomic and somatomotor components. The autonomic component focuses on a myelinated branch of the vagus nerve with a source nucleus located in the nucleus ambiguus of the medulla. The somatomotor component involves the neural regulation of the striated muscles of the face and head via special visceral efferent pathways traveling through five cranial nerves (i.e., V, VII, IX, X, XI). The myelinated vagus provides efferent control over the heart by regulating the sinoatrial node (“pacemaker” of the heart). RSA allows for the quantification of myelinated vagal control of the heart by measuring the fluctuations in heart rate (HR) during spontaneous breathing (Porges, 1995).
To promote effective social communication, the myelinated vagus actively inhibits intrinsic HR (~100–150 beats per min). Higher RSA reflects greater myelinated vagal control of the heart, which in turn suggests a soothed autonomic state that is theorized to promote social communication. In contrast, lower RSA indicates reduced myelinated vagal control that may potentiate defensive behaviors (e.g., fight/flight) and interfere with the ability to regulate behavioral state to spontaneously socially engage. As such, RSA gives a noninvasive index of a neurophysiological state that is related to social behavior.

Due to communication in the brainstem between neural circuits that control the heart and the face, RSA provides insight into the functional features of the neural circuits that regulate the striated muscles of the face and head (i.e., cranial nerves V, VII, IX, X, and XI; see Porges, 2009). These cranial nerves are involved in facial expression (i.e., cranial nerves V and VII), ingestion (cranial V), listening (cranial nerves V, VII), vocalizations (cranial nerves IX and X), and head gestures (cranial nerve XI), in addition to other functions not exclusive to social behavior (e.g., cranial nerve V is involved in ingestive processes such as sucking, chewing, and swallowing). The centralized origin of these cranial nerves in the brainstem provides a neuroanatomical face–heart connection that can function as an integrated social engagement system (Social Engagement System; Porges, 2001, 2003a, 2007b, 2009; Porges & Lewis, 2009). RSA provides a broad index of the functioning of the Social Engagement System cranial nerves and thus, may provide important insights into ASD, where effective social behavior is compromised.

NEUROPHYSIOLOGICAL CORRELATES OF SOCIAL BEHAVIOR IN ASD

The diagnostic criteria for ASD outlined in the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR; American Psychiatric Association, 2000) specifically note behaviors that are controlled by the Social Engagement System: (1) marked impairment in the use of nonverbal behaviors including eye-to-eye gaze, facial expression, body postures [cranial nerves VII, XI]; (2) lack of spontaneous seeking to share enjoyment, interests, or achievements [cranial nerves VII, IX, X, XI]; (3) delay in, or total lack of, the development of spoken language or marked impairment in the ability to initiate or sustain a conversation with others [cranial nerves X, IX]. Although the special visceral efferent pathways that travel through these five cranial nerves are involved in the regulation of various bodily functions, they also contribute to an emergent Social Engagement System involved in several features of social behavior. The link between RSA and the Social Engagement System provides strong motivation to evaluate the relation between RSA and social behavior in ASD.

Prior studies have evaluated the relationship between other cardiovascular variables, such as HR, heart period (HP), or heart rate variability (HRV), in children with ASD (e.g., MacCulloch & Williams, 1971). Few studies, however, have examined RSA and social behavior in children with ASD. Recent studies have found evidence that RSA is correlated with positive social functioning in ASD. Specifically, Bal et al. (2010) reported that children and adolescents (aged 7–17 years old) with Autistic Disorder or Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), who had higher amplitude RSA at baseline, were better at recognizing emotions. Similarly, Van Hecke et al. (2009) reported that children with ASD (aged 8–12) with higher baseline RSA had better social skills and fewer parent-reported behavior problems.

Both studies demonstrated that higher RSA was a marker of more positive social functioning in children with ASD. Therefore, the behavioral features of the Social Engagement System may be more coordinated when children with ASD have greater vagal regulation of the heart (i.e., higher amplitude RSA), thereby producing more appropriate social abilities.

Cognitive Ability and RSA

Beyond the correlation between RSA and social functioning, RSA is a broad indicator of overall functioning in typically developing populations (Thayer & Lane, 2009), and is most likely a global indicator of such functioning in ASD as well. RSA is linked with cognitive ability in typically developing populations. Specifically, the ability to reduce RSA amplitude in response to attentive demands is positively associated with cognitive function, including better processing speed, working memory, learning, and receptive language skills (Beauchaine, 2001; Morgan, Atkins, Steffian, Coric, & Southwick, 2007; Staton, El-Sheikh, & Buckhalt, 2008; Watson, Baranek, Roberts, David, & Perryman, 2010). Individuals who display both high tonic RSA and greater RSA suppression to attention-demanding stimuli are thought to engage and attend more effectively with stimuli, therefore producing higher cognitive performance and ability (Thayer & Lane, 2000).

For example, higher RSA amplitude in infants is associated with more optimal performance on tasks requiring sustained attention (Richards, 1985) and visual
memory recognition (Linnemeyer & Porges, 1986). Similar to these findings, RSA is a marker of positive cognitive functioning in children at later ages (Watson et al., 2010). Specifically, in 3–5 year olds, RSA suppression during classroom tasks demands was positively correlated with on-task behavior in the classroom, which in turn was associated with better executive functioning during a peg turning task and Stroop-like task (Blair, 2003). Furthermore, executive control was found to have a positive correlation with RSA amplitude in children and adolescents (aged 6–16), as measured during a Stroop color-word task, stop signal task, trail-making task, and redirections to task (Mezzacappa, Kindlon, Saul, & Earls, 1998). RSA amplitude also predicted cognitive performance on the fluid intelligence scales of the Woodcock–Johnson III (i.e., processing speed, working memory, cognitive efficiency, verbal ability) in school-aged children (Staton et al., 2008). These studies attest to the robustness of the relationship between RSA and cognitive functioning, which is maintained when confounding variables are controlled (e.g., age, sex, and puberty status; Staton et al., 2008).

Due to the delays in language that characterize ASD (American Psychiatric Association, 2000) and the high correlation of language ability to IQ (Tannenbaum, Torgesen, & Wagner, 2006), examining the relationship between RSA amplitude and language ability may help elucidate some neurophysiological processes underlying language abnormalities in ASD. Receptive language, or the ability to comprehend spoken vocabulary words, may be especially important in the context of the Social Engagement System. Since the regulation of the middle ear muscles via the trigeminal and facial nerves dampen acoustic energy at low frequencies, adequate contraction of the middle ear muscles would allow the individual to discriminate the human voice from background noise (see Porges & Lewis, 2009). In turn, this would promote auditory comprehension. Despite this importance, only one study was found that related receptive language ability to RSA. Watson et al. (2010) reported that, in typically developing children, higher RSA amplitude (collected during a child-directed speech task) was associated with better receptive language ability.

Attention and RSA

Not only is ASD characterized by language difficulties, but also by difficulties with attention (Dawson et al., 2004; Landry & Bryson, 2004) that are evident as young as 6 months old (Maestro et al., 2002). In particular, children with ASD show attention impairments to social stimuli, including joint attention (Dawson et al., 2004), which is related to cognitive difficulties (Loveland & Landry, 1986). In typically developing individuals, physiological response patterns contribute to attention abilities (i.e., higher RSA amplitude and greater RSA suppression during attention-demanding tasks contribute to effective engagement with stimuli). Yet, little is known regarding neurophysiological response patterns to attention-demanding tasks in ASD.

As noted above, individuals with higher RSA amplitude and greater RSA suppression have a better ability to engage and disengage with demands in the environment as needed (Thayer & Friedman, 2004; Thayer & Lane, 2000). Further, high tonic RSA amplitude predicts more rapid recovery when demands are removed (Porges, 1991). Basal RSA is also associated with better attention in children and infants. For example, typically developing fourth and fifth graders with higher baseline RSA amplitude performed better on the continuous performance test relative to children with lower baseline RSA (Suess, Porges, & Plude, 1994). In infants, basal RSA was associated with the ability to sustain attention to visual stimuli (Richards, 1985).

In general, greater cardiac vagal control, reflected in basal RSA amplitude and task dependent RSA suppression, may be a protective factor reducing the risk of developing psychopathologies, particularly those associated with social behavior (Porges, 2007b). In a longitudinal study of interest, RSA during an attention-demanding task (child directed speech) in toddlers with ASD predicted concurrent and later communication skills (Watson et al., 2010). As such, it is of value to study RSA reactivity to attention-demanding tasks in ASD.

Moreover, RSA is also positively associated with emotion regulation and other self-regulatory attributes that are crucial to effective social engagement (Porges, 2011). That RSA reflects such a wide range of psychological functions is a consequence of its position at a key nexus of bi-directional central-autonomic interactions (Thayer & Lane, 2009). RSA serves as a meter of the integrity of a neural system that broadly regulates organism–environment transactions. Hence, it is likely that RSA deficits will be present across a broad range of psychopathologies, in that many diagnostic categories share common psychological dysfunctions (Friedman & Thayer, 1998; see van Praag, Asnis, Kahn, & Brown, 1990).

HYPOTHESES

Consistent with literature reviewed above, we predicted that (1) higher basal RSA would correlate with more
positive functioning in children with ASD as measured by better social functioning (i.e., joint attention, conventional gestures), and (2) higher receptive language ability, and (3) that children with high versus low basal levels of RSA would show appropriate vagal suppression and recovery to attention-demanding tasks. To test these hypotheses of RSA as a global measure of functioning in ASD, we examined the relationship between basal RSA and social functioning (i.e., during a semi-structured play task) and receptive language. In addition, we investigated the response pattern of RSA and HP during an attention-demanding task (i.e., listening to music or an audiobook).

METHOD

Participants

Twenty-three children (18 males, 5 females), aged 4 years 3 months to 7 years 9 months, with a prior diagnosis of an ASD (i.e., Autism, n = 12; Asperger’s Disorder, n = 10; PDD-NOS, n = 1) and no severe tactile hypersensitivities, were sampled from the Southwest Virginia area. Children with severe tactile hypersensitivities were excluded from the study because adhesive electrodes were used to collect cardiovascular data. Informed consent was obtained from all parents. The Institutional Review Board at Virginia Tech approved the project. ASD diagnoses were independently established by trained professionals in the community prior to being enrolled in the study. Most children had Social Responsiveness Scale (SRS; Constantino et al., 2003) scores in the severe range (T-score ≥76; n = 17). Scores in the severe range are strongly related to a clinical diagnosis of Autistic Disorder, Asperger’s Disorder, and PDD-NOS. The remaining participants (T-score = 60–75; n = 6) fell in the mild to moderate range for social difficulties, which are typical for children with high-functioning Asperger’s Disorder or PDD-NOS. Overall, SRS T-scores ranged from 64 to ≥90 (M = 81.13, SD = 8.00) with a mode score of ≥90 (n = 7); thus, all scores indicate clinically significant deficiencies in reciprocal social behavior. Further, the SRS is highly correlated to the Autism Diagnostic Interview-Revised, a gold standard diagnostic tool for autism (Constantino et al., 2003). Receptive vocabulary scores, measured by the Peabody Picture Vocabulary Test (PPVT-III), served as the measure of cognitive functioning and scores ranged from 20 (extremely low) to 129 (moderately high). See Table 1 for further characterization of ASD symptomatology for the sample, according to a list of items administered to parents adapted from the Autism Research Institute. Participants were recruited through the university autism clinic, electronic autism listservs, e-mails to local autism organizations, and parent support groups.

Twenty-one primary caregivers reported their child’s race as White, one parent reported their child’s race as Asian, and one parent did not report their child’s race. Most parents reported their highest education as a college degree or beyond: high school graduate (n = 1), some college (n = 5), college degree (n = 10), some graduate studies (n = 2), graduate degree (n = 4). Fifty-three percent of primary caregivers reported an annual household income below $60,000.

Experimental Design and Procedures

The data reported herein are part of a protocol that assessed autonomic responses to different auditory inputs (i.e., music vs. audiobook). Since preliminary analyses indicated that autonomic reactivity to the two conditions did not differ, the data were collapsed across conditions and treated in the statistical analyses as one attention-demanding task. The experimental laboratory sessions described below were held at a university-based clinic in Southwest Virginia.

Cardiac variables (RSA and HP) were recorded during the following stationary activities: 3-min baseline video, 12-min attention-demanding task, and 3-min recovery video. Social engagement was measured during the participant’s semi-structured play with the examiner before (10 min) and after (10 min) the attention task. The frequencies of specific social behaviors (see Behavioral Coding section for details) were coded from digital video with The Observer XT (Version 8.0, Noldus Information Technologies, Wageningen, The Netherlands). Primary caregiver(s) completed questionnaires while watching their child participate in the study through a one-way mirror.

A phone interview was conducted with the child’s primary caregiver prior to the experimental session. During the interview, the primary caregiver was asked for verbal assent, informed about the in-lab experimental procedures, and administered the Short Sensory Profile to assess for tactile and auditory hypersensitivities. The experimenter also verbally confirmed a prior diagnosis of an ASD in the child.

Informed consent was obtained from the parents and participants upon their arrival to the clinic and prior to the start of the experimental procedures. After consent was obtained from the parent and verbal assent was obtained from the child (if capable), the parent was instructed to complete questionnaires while watching their child behind a one-way mirror.

After the parent left the room, the experimenter administered a test of receptive vocabulary (PPVT-III). The Life-Strip (Vivometrics, Ventura, CA), the device used for physiological data acquisition, was then attached to the child. The child then watched a 3-min baseline video, National Geographic’s Animal Holiday, a nature video geared for children 4–10 years old, which served to achieve a “vanilla” baseline recording period (Jennings, Kamarck, Stewart, Eddy, & Johnson, 1992). The social interaction communication scales (SICS; Bzhenova, 2006) were administered by the experimenter (10 min). After the SICS, the child listened to either five self-selected songs in random order for 12 min or one 12-min, non-music section of a self-selected audiobook. Since the audiobook or songs were self-selected, the audiobooks and songs were not the same for each child. Although this introduced variation into the study, the children were asked to self-select the music or audiobook to maximize each child’s attention to the task and effect on physiological response, which has been shown to occur in prior studies.
After the auditory attention tasks, the child was administered the SICS and watched the 3-min section of the nature video during a recovery period. The LifeShirt™ (see below for details) was removed and any questions the parent or child had about the study were answered.

Parent Questionnaires

**Short Sensory Profile (Dunn, 1999).** This 38-item questionnaire uses a 5-item Likert scale (1 = Always to 5 = Never) to distinguish between sensory symptoms often found in children with ASD. Children with severe tactile hypersensitivity were excluded from this study due to the use of adhesive electrodes that attach to the skin. Scores were summed in each domain to determine a child's score. For this study, internal consistencies were: tactile sensitivity (Cronbach’s α = .71) and visual/auditory sensitivity (Cronbach’s α = .47).

**Social Responsiveness Scale (SRS; Constantino & Gruber, 2007).** This 65-item questionnaire uses a 4-item Likert scale from “1” (Never true) to “4” (Almost always true) to measure social impairments, social awareness, social information processing, capacity for reciprocal social communication, social anxiety/avoidance, and autistic preoccupations and traits (Constantino & Gruber, 2007). The SRS was used to characterize the sample on ASD symptoms, since it is highly correlated with the Autism Diagnostic Interview-Revised (ADI-R), a gold standard diagnostic tool for autism (Constantino et al., 2003). Scores on the SRS were summed to create an overall total score that indicates the severity of social deficits. The total score and five subscale scores had the following internal consistencies, as assessed by Cronbach’s α: total score = .93; social awareness = .63; social cognition = .75; social communication = .78; social motivation = .70; autistic mannerisms = .73.

Child Measures

**Peabody Picture Vocabulary Test, Third Edition (PPVT; Dunn, 1997).** The PPVT-III measures receptive language skills (understanding and comprehension of spoken words) for individuals aged 2 years, 6 months to 90+ years. Age-based standard scores were used to measure receptive language ability. The PPVT-III is significantly correlated to the Vocabulary Comprehension Index on the Wechsler Intelligence Scale for Children, Third Edition, r = .75, p < .01 (Tannenbaum et al., 2006) and demonstrates good psychometric properties (Williams & Wang, 1997).

**Social Interaction Communication Scales (SICS; Bazhenova, 2006).** The SICS is a 10-min, semi-structured, play-based, observational assessment of social engagement skills in 2–6 year olds (Bazhenova, 2006). The experimenter presented various toys (e.g., balloons, bubbles, hat) and the child was observed playing with the toys and interacting with the experimenter (e.g., using eye contact, sharing information, using gestures). The toys were presented in a flexible manner; some were repeated at the child’s request.

Two researchers used The Observer® XT (Version 8.0, Noldus Information Technologies, Wageningen, The Netherlands) to code the number of sharing behaviors and

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**Table 1. Frequency and Percent of Sample Size (N = 23) of Endorsed Parent-Reported ASD Symptoms**

<table>
<thead>
<tr>
<th>Qualitative abnormalities in reciprocal social interaction</th>
<th>Frequency</th>
<th>% of N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Has trouble joining a group</td>
<td>13</td>
<td>56.52</td>
</tr>
<tr>
<td>Happier left alone</td>
<td>8</td>
<td>34.78</td>
</tr>
<tr>
<td>Poor eye contact</td>
<td>11</td>
<td>47.83</td>
</tr>
<tr>
<td>Does not respond when called</td>
<td>9</td>
<td>39.13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qualitative abnormalities in communication</th>
<th>Frequency</th>
<th>% of N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expressive language delay</td>
<td>14</td>
<td>60.87</td>
</tr>
<tr>
<td>No verbal language</td>
<td>5</td>
<td>21.74</td>
</tr>
<tr>
<td>Echolalia</td>
<td>9</td>
<td>39.13</td>
</tr>
<tr>
<td>Absent or limited gestures</td>
<td>3</td>
<td>13.04</td>
</tr>
<tr>
<td>Sustained odd play</td>
<td>4</td>
<td>17.39</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Restricted, repetitive, and stereotyped patterns of behavior</th>
<th>Frequency</th>
<th>% of N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hums frequently</td>
<td>7</td>
<td>30.43</td>
</tr>
<tr>
<td>Insists on sameness</td>
<td>10</td>
<td>43.48</td>
</tr>
<tr>
<td>Agitated when routine is disrupted</td>
<td>13</td>
<td>56.52</td>
</tr>
<tr>
<td>Insists on precision</td>
<td>4</td>
<td>17.39</td>
</tr>
<tr>
<td>Fixation on objects or topics</td>
<td>12</td>
<td>52.17</td>
</tr>
<tr>
<td>Hand flapping</td>
<td>11</td>
<td>47.83</td>
</tr>
<tr>
<td>Toe walking</td>
<td>4</td>
<td>17.39</td>
</tr>
<tr>
<td>Spinning self</td>
<td>4</td>
<td>17.39</td>
</tr>
<tr>
<td>Likes to watch objects spin</td>
<td>5</td>
<td>21.74</td>
</tr>
<tr>
<td>Rhythmic or rocking behaviors</td>
<td>2</td>
<td>8.70</td>
</tr>
</tbody>
</table>
conventional gestures were coded independently. Discrepant codes then were resolved through a consensus of the coders. Sharing was defined as directing positive emotions, sharing information, joint attention, and showing/sharing toys with the examiner. Conventional gestures were coded as gestures used to convey a message to the examiner (e.g., shaking head, shrugging shoulders, pointing). Joint attention (child sharing) and conventional gestures were both of particular interest in this study due to the interactional nature of these social behaviors. Joint attention and conventional gestures both require the participant to have an understanding of the other to show, share, and direct objects and/or information to the examiner. As such, it is not surprising that the initiation of joint attention in infancy negatively predicts withdrawn behavior and positively predicts social competence (Sheinkopf, Mundy, Claussen, & Willoughby, 2004).

Data Reduction of Cardiovascular Data
The LifeShirt® (Vivometrics, Ventura, CA) continuously recorded HP throughout the experimental session. The LifeShirt®, worn like a vest or shirt, shields, electrodes, electrode wires, and respiration straps from the wearer’s view and provides a comfortable apparatus for children with ASD. Three Ag/AgCl neonatal electrodes (3M™, St. Paul, MN) were placed on the child’s chest in a Lead II configuration.

HP data were edited using CardioEdit (Brain-Body Center, University of Illinois at Chicago). These data were visually inspected off-line for outliers; faulty HPs were detected, edited, and adjusted. These infrequent outliers, which were caused by missed R-wave identification (e.g., interbeat interval too long = 2 s), faulty identification of an R-wave (e.g., interbeat interval too short = .1 s), or ventricular arrhythmias, were identified and edited via integer arithmetic (i.e., adding short periods together or dividing long periods). Due to missing data from movement artifact, 20 participants had complete RSA and HP data for each epoch (i.e., baseline, task recovery). Due to movement artifact during certain 30-s epochs (particularly the last 30 s of the attention-demanding task), the listwise sample size for RSA and HP was $N = 15$.

After outliers were edited, data were analyzed using CardioBatch (Brain-Body Center, University of Illinois at Chicago). CardioBatch incorporates algorithms that extract the heart rate variance within the frequencies of spontaneous breathing to operationally define RSA amplitude (Porges, 1985; Porges & Bohrer, 1990). Based on these algorithms, sequential heart periods were re-sampled every 250 ms to generate a time series of values at equal intervals. To assess RSA in children, a frequency band of .24–1.04 was used. This frequency band effectively captures the range of spontaneous breathing in children (Bal et al., 2010). Cardiac variables were analyzed from the following experimental tasks: 3-min baseline, 12-min attention task, 3-min recovery. For each experimental task, cardiac data were analyzed in sequential 30-s epochs. For the baseline and recovery periods, all 3-min were analyzed in 30-s epochs and the means of the baseline and recovery epochs were used in the data analyses. For the task periods, the first 3 min (task 1; min 1–3) and last 3 min (task 2; min 10–12) were calculated by averaging 30-s epochs to examine reactivity across the attention-demanding stimuli.

DATA ANALYSIS
Correlations were calculated to examine the relationships among social, receptive language, HP, and RSA variables. To examine RSA and HP reactivity to the attention-demanding stimuli, repeated measures analyses of variance were conducted. In these analyses, child age (in months) was used as a continuous covariate because it was significantly correlated with baseline HP, $r = .44, p = .04$, and marginally correlated with baseline RSA, $r = .35, p = .11$. In order to illustrate the change in HP and RSA response patterns over time, a repeated measures ANOVA was conducted (baseline, task 1, task 2, recovery). Correlations were calculated between baseline RSA and change scores for RSA and HP (differences in task 1 and baseline, task 2 and baseline, and recovery and task 2).

RESULTS
Data were analyzed to determine if baseline RSA amplitude and baseline HP were differentially associated with receptive language functioning, communicative gestures, and child sharing (all of which were measured before the attention task). Descriptive statistics (mean, $SD$) are reported for each variable in Table 2. Additionally, data were analyzed to assess the relation between baseline RSA and HP reactivity to the attention-demanding task (i.e., listening to auditory stimuli). Sensory subscales were not correlated with RSA or HP.

Relationship of Baseline Cardiovascular Activity With Social Functioning and Receptive Language
See Table 3 for correlations between baseline RSA, baseline HP, PPVT, SRS scores, conventional gestures, and child sharing. Results indicated that baseline RSA was significantly correlated with conventional gestures, $r = .60, p = .004$, and child sharing on the SICS, $r = .48, p = .03$, such that higher RSA amplitude was associated with more pro-social behavior. Baseline HP did not show a significant correlation with child sharing. However, baseline HP was significantly correlated with conventional gestures, $r = .65, p < .001$, such that longer HP (i.e., slower HR) was associated with more communicative gestures. Baseline RSA and HP were not significantly correlated with the SRS total score or its subscales, though values were generally in
the direction of slower heart rate and higher amplitude RSA associated with lower SRS scores.

The correlation between receptive language functioning (PPVT-III standard score) and RSA was significant, $r = .44, p = .04$, with better receptive language related to higher RSA amplitude. Baseline HP was not significantly correlated with receptive language.

Cardiovascular Reactivity to an Attention-Demanding Task

A repeated measures ANOVA was conducted to assess RSA and HP reactivity over time (baseline, task 1, task 2, recovery; Fig. 1). Due to the correlation between age and HP (see above), baseline age in months was used as a continuous covariate. Correlations were conducted between baseline RSA and reactivity change scores from baseline to task 1, task 2, and recovery for HP and RSA. The pattern of RSA response over time (baseline, task 1, task 2, recovery) was significant, $F (1, 14) = 4.68, p = .02, \eta^2 = .56$. The pattern of HP reactivity over time (baseline, task 1, task 2, recovery) was nonsignificant, $F (1, 14) = 1.98, p = .18, \eta^2 = .35$. The patterns of RSA and HP are illustrated in Figure 1, RSA and HP demonstrated suppression to the attention-demanding task and increase at recovery.

Baseline RSA was correlated with individual differences in changes in both RSA and HP from baseline to task 1 and changes from baseline to task 2. Baseline RSA was not related to changes from task 2 to recovery. As reported in Table 4, high baseline RSA was associated with greater reduction in RSA and HP during the task.
DISCUSSION

We examined the relationship between baseline RSA and social functioning (i.e., joint attention and conventional gestures), receptive language ability, and physiological response to attention-demanding tasks in children with ASD. RSA was positively correlated with experimenter-observed joint attention and conventional gestures, and receptive language ability. Furthermore, children with higher RSA amplitude at baseline exhibited a pattern of RSA responding consistent with prior studies on typically developing children (i.e., a greater suppression in RSA during the attention-demanding task). These findings build on the emerging ASD literature examining RSA, social functioning, language ability, and physiological responsivity to attentional tasks. As such, the present findings converge on a consistent pattern of results that link RSA to positive social-cognitive function in ASD. Moreover, these data stress the importance of RSA in future research studying the biobehavioral features of ASD and other psychopathologies associated with social and cognitive difficulties.

Consistent with prior literature correlating social behavior and RSA in ASD (Bal et al., 2010; Van Hecke et al., 2009), baseline RSA amplitude was significantly correlated with the spontaneous production of more conventional gestures and joint attention. Baseline HP was significantly related to conventional gestures, with longer HP (i.e., slower HR) being associated with more conventional gestures. Baseline HP, however, was not significantly correlated with joint attention; thus, RSA was related to joint attention independent of HP.

Similar to the relationship with joint attention, higher RSA amplitude, and not HP, was related to better receptive language functioning. Findings of the positive relationship between cognitive functioning and RSA are consistent with prior findings in both ASD and typically developing children (Blair, 2003; Mezzacappa et al., 1998; Staton et al., 2008).

After establishing functional profiles of children with ASD, such that those with higher basal RSA amplitude showed both better social functioning and receptive language skills, we examined RSA and HP reactivity to an attention-demanding task. More effective engagement with and attention to the environment is associated with higher basal RSA and greater RSA suppression (vagal withdrawal) during attention-demanding tasks (Thayer & Lane, 2000). Children with higher basal RSA amplitude were predicted to show more RSA suppression during the attention-demanding task. Consistent with these predictions, children with higher basal RSA amplitude were related to joint attention independent of HP.

![Graph showing change over time in RSA and HP](image)

**FIGURE 1** Change over time in respiratory sinus arrhythmia (RSA) and heart period.

Table 4. Correlations Between Baseline RSA and Change Scores for RSA and HP: Task 1-Baseline, Task 2-Baseline, Recovery-Task 2

<table>
<thead>
<tr>
<th></th>
<th>Baseline RSA</th>
<th>Task 1-Baseline RSA</th>
<th>Task 2-Baseline RSA</th>
<th>Recovery-Task 2 RSA</th>
<th>Task 1-Baseline HP</th>
<th>Task 2-Baseline HP</th>
<th>Recovery-Task 2 HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline RSA</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 1-Baseline RSA</td>
<td>-.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Task 2-Baseline RSA</td>
<td>-.53&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.40</td>
<td>1.00</td>
<td></td>
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<tr>
<td>Recovery-Task 2 RSA</td>
<td>.07</td>
<td>-.16</td>
<td>-.33</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Task 1-Baseline HP</td>
<td>-.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.82&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.33</td>
<td>.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 2-Baseline HP</td>
<td>-.53&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.33</td>
<td>.82&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.44</td>
<td>.54&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Recovery-Task 2 HP</td>
<td>.06</td>
<td>-.32</td>
<td>-.22</td>
<td>.77&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-.57&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-.35</td>
<td>1.00</td>
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<sup>a</sup>Correlation is significant at the .05 level (2-tailed).
<sup>b</sup>Correlation is significant at the .01 level (2-tailed).
which predicts that, “…the higher the initial value… the higher the response to function-depressing stimuli” (Wilder, 1967). However, in the current experiment RSA reflects a level of vagal regulation of the heart and a “higher” level of vagal regulation would be predictive of greater changes in the variables (i.e., RSA and HP) assumed to be mediated by vagal regulation during task demands. Consistent with this “neural” explanation, both the baseline level of RSA and the changes in RSA and HP during the experimental protocol would represent dynamic changes in vagal influence to the heart and are strongly correlated.

Notably, a similar pattern of results was found for HP and RSA on the outcome variables. For example, RSA and HP were positively related to receptive language ability, but only RSA was significantly correlated with receptive language ability. Due to the potent influence vagal tone has on resting cardiac rate, RSA and HP generally show a high correlation, as they did in this study (see Table 3). Thus, it is not surprising that the two measures yielded similar results. However, highly correlated measures are not necessarily interchangeable because they may differ in their physiological underpinnings and sensitivity to individual differences (Porges, 2007a). RSA and HP demonstrate this principle, in that RSA is a relatively pure vagal measure, but tonic (i.e., baseline) HP has both sympathetic and parasympathetic influences. Moreover, the significant correlation between RSA and receptive language ability, joint attention, and conventional gestures suggests that RSA may provide more insight than HP to global functioning through measurement of the vagus. For example, with respect to social functioning, the vagus seems to provide better insight to social functioning related to the cranial nerves articulated in the Polyvagal Theory (Porges, 2011). Additionally, joint attention as defined by Bazhenova (2006) is an amalgamation of behaviors controlled by the Social Engagement System’s five cranial nerves, such as cranial nerve XI, which coordinates the movement of head turning muscles to orient to the examiner. As suggested by the Polyvagal Theory, and shown in this present study, insight to the vagus (via RSA) may give information regarding brainstem functioning that can facilitate effective environmental engagement, including social functioning (see Porges, 2007a, for an extended treatment of the RSA-HP relationship).

The current study had several limitations. First, the sample size was relatively small. This limit on statistical power may have restricted the ability to find significant time effects across the baseline and attention-demanding task for RSA or HP, though significant interactions did appear depending on initial RSA level. Notably, significant task to recovery changes in both RSA and HP were not observed. We did not confirm that RSA patterns during the attention-demanding task were indicative of auditory attention (e.g., via behavioral coding) due to the difficulty of measuring auditory attention to stimuli in an objective fashion. This could be addressed in future studies by examining the neural correlates during RSA measurement to attention-demanding stimuli.

The previously reported relationships between parent self-reported social skills and basal RSA amplitude were not replicated (Van Hecke et al., 2009). The significant correlations between RSA amplitude and social behavior reported in the latter study, however, were obtained with the Social Skills Rating System (SSRS; Gresham & Elliot, 1990), rather than with the instrument used the current study (i.e., the SRS). Although observed behavioral ratings between social behavior and RSA amplitude were confirmed in the present study, the relation between parent perceptions assessed with the SRS and RSA amplitude were not, despite the high correlation between the SRS and SSRS (Lerner, Hutchins, & Prelock, 2011). In addition to the possible explanations of low power to detect the effect, perhaps the experimenter-observed measures were more powerful than the SRS in that they reflected actual performed behavior, as opposed to parent perceptions. Additionally, the experimenter-observed measures may have been more appropriate for the younger age range in this study relative to prior studies that used the SSRS. Another possible explanation for the lack of findings related to the SRS is that the observed measures of social functioning (i.e., gestures and shared attention) are more specifically tied to the functioning of the cranial nerves associated with the Social Engagement System. Additional research is needed in order to test these possibilities.

The patterns of findings presented here were not compared to typically developing children. This limits the interpretation of the presented findings, but also invites other researchers to use control groups in their experimental design. By including typically developing children, this would create a more comprehensive understanding of RSA as a global marker of functioning and the differences/similarities that exist between typically developing and ASD populations. In addition, future studies should characterize their ASD population with gold-standard diagnostic tools, such as the ADI-R, although parent-reported social symptoms associated with ASD are included in the SRS, which is highly correlated with the ADI-R (Constantino et al., 2003). The majority of participants had SRS scores in the severe range and demonstrated significant impairment by parent-report of ASD symptomatology (Table 1), no other characterization data were collected (e.g.,
chart review, contact with diagnosing provider). This should be improved upon in future studies.

Due to these limitations, the present results should be viewed as preliminary. However, they are of import in identifying the neurophysiological and biobehavioral features related to the compromised social, cognitive, and physiological functioning associated with ASD. Specifically, these findings support the continued use of vagal measures such as RSA to elucidate the neurophysiological mechanisms depicted in the Polyvagal Theory that are associated with social-cognitive difficulties. Such research may have implications for future interventions targeting the vagus, through both invasive (e.g., vagal nerve stimulation) and noninvasive (e.g., breathing exercises, biofeedback) procedures that may lead to improved attention, social, and cognitive functions.

In sum, this study builds on the nascent ASD-RSA literature and provides preliminary evidence associating RSA with social behavior, receptive language ability, and physiological reactivity to attention-demanding stimuli. The results highlight the importance and utility of RSA as a global marker of positive functioning in young children with ASD, and the potential to target the measures of vagal function as an outcome variable in studies evaluating interventions for children with ASD.

NOTES

The authors would like to thank: Dr. Julie Dunsmore, Dr. Thomas Ollendick, Elgiz Bal, Conrad Baldner, Katie Lansing, Douglas McKeown, Maggie Mooney, and Chad Stephens for their assistance with this study. This research was supported by a graduate grant from the Organization for Autism Research.

REFERENCES


