Title
RESPIRATORY SINUS ARRHYTHMIA PREDICTS SOCIAL PROBLEM-SOLVINGBEHAVIORS IN CHILDHOOD

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RESPIRATORY SINUS ARRHYTHMIA PREDICTS SOCIAL PROBLEM-SOLVING BEHAVIORS IN CHILDHOOD

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Abstract

The parasympathetic nervous system (PNS) enables people to regulate their stress and return to homeostasis after challenging experiences. They may also engage in social problem-solving behaviors - expressed positive affect, speech, laughter, and approach - to process or change a social stressor. We examined if baseline respiratory sinus arrhythmia (RSA), a measure of PNS function, predicted children's social problem-solving behaviors. 170 children between the ages of 4 and 12 years (50% boys) completed a lab-based task in which they were unexpectedly faced with an individual wearing a scary mask who behaved oddly and was unresponsive to the child's bids for social engagement. We coded four specific social problem-solving behaviors, including expressed positive affect, speech, laughter, and approach. Resting cardiac physiology served as an index of children's emotion regulation capacity. We hypothesized that children with higher resting RSA would demonstrate more social problem-solving behaviors. Our results suggested a marginal relationship between resting RSA and social problem-solving behaviors, meaning as baseline resting RSA increased, children spent more time engaged in social problem-solving behavior during the episode. Age was also a significant covariate when analyzed alongside resting RSA. This study reinforces the importance of considering developmental psychophysiology.

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RSA Predicts Social Problem-Solving Behaviors in Childhood

When presented with a stressful situation, the autonomic nervous system signals to the body that it is in danger and therefore must prepare to respond. The autonomic nervous system, which consists of the sympathetic (SNS) and parasympathetic (PNS) nervous systems, is a key aspect of emotion regulation as it dictates the physiological response to stressful stimuli. While everyone has these coordinated branches of the nervous system to assist in facing emotional challenges, there are considerable differences in each person's behavioral response to stress.

The way people cope with stress is closely connected to the way they perceive control in a situation (Compas et al., 1991). In the case of a stressful experience, an individual would perceive the stressor, evaluate it as personally relevant, and determine it is a challenge or a threat, all of which are appraisals of the stressor's potential impact on someone's well-being. A challenge or threat appraisal refers to when someone views a stressful situation as being within or beyond their ability and resources to cope, respectively. Being in an unfamiliar social situation may cause children to have less perceived control and therefore experience more emotional distress. One study revealed that children who were more effective at self-regulating during emotion-eliciting tasks utilized more positive appraisal and active coping when navigating their own challenges (Zalewski et al., 2011). The children in this study appraised the lab tasks as challenges to be navigated rather than threats to be dreaded and simultaneously employed cognitive and behavioral efforts to address them.

This sequence of cognitive appraisals gives rise to differing responses from the SNS and PNS. The SNS is responsible for producing what is commonly known as the "fight or flight" response when faced with a threat as it redistributes metabolic output by increasing cardiac output and changing blood flow to vital organs (Diamond & Cribbet, 2013). On the other hand, the PNS is responsible for producing the "rest and digest" response after facing a threat as it focuses on the restoration of internal organs through physiological changes such as decreased heart rate and blood pressure (Diamond & Cribbet, 2013). These two systems work in tandem to maintain equilibrium within the human body during times of stress, helping individuals regulate their physiological and emotional changes.

People may respond physiologically differently to stressors and emotional challenges based on their appraisal of the environment. For example, Porges (2009) notes that individuals demonstrate social engagement and calmer states when they determine an environment is safe, thereby inhibiting sympathetic activation (i.e. increased PNS response); on the other hand, others may appraise an environment as dangerous even when it is safe, resulting in states that enable fight, flight, or freeze behaviors (Porges, 2009). The process of distinguishing safe from unsafe contexts to enable engagement in social behaviors relies on the assumption that social communication can be efficiently expressed only when the SNS response is inhibited (Porges, 2009). Appraisal is therefore a necessary process through which individuals respond to stress; in determining the nature of a stressor, the body can appropriately respond through SNS activation or inhibition. In other words, the combination of psychology (appraisal of one's environment) and physiology (autonomic nervous system activity) may result in different behavioral responses to stress.

To evaluate autonomic nervous system activity, researchers have utilized respiratory sinus arrhythmia (RSA). RSA is a measure of PNS function that refers to the changes in heart rate that are correlated with breathing, and it is largely determined by vagus nerve influences on the heart (Butler et al., 2006). In other words, this measure is an index of PNS-mediated cardiac control (Beauchaine, 2015) and can be associated with the PNS response. It serves as a useful measure of parasympathetic activity in determining the relationship between individuals' resting RSA values and the behaviors they express in stressful environments.

Respiratory Sinus Arrhythmia as an Index of Emotion Regulation Capacity

Emotion regulation refers to the set of psychological processes by which individuals can direct attention, shape emotional experiences through cognitive appraisals, and cope with physiological responses (Koole, 2009). By extension, emotion regulation also encompasses someone's ability to affect the intensity and length of their emotional episodes. To go one step further, the ability to cope with stress, or self-regulate, allows an individual to use functional, context-dependent behaviors in response to emotional challenges. What scholars refer to as emotion regulation, therefore, includes a variety of functions that help an individual manage their emotional, mental, and physical well-being.

Porges and colleagues (1994) assert that changes in RSA in response to challenges represent physiological changes that support the expression of emotion by regulating metabolic output (i.e. changes in heart rate). With this in mind, vagal control contributes to an individual's capacity to regulate their emotions; those who exhibit increased vagal control are more capable of facing situations that cause stress due to their ability to adapt well to different situations. Some researchers further suggest that children who lack the physiological flexibility to modify vagal tone in response to situational challenges also lack the flexibility required for successful emotional self-regulation (Santucci et al., 2008). In particular, researchers examined vagal tone in children ages 4-7 during rest, during an emotional challenge (reactivity), and after a frustration task (recovery) and found that lower vagal recovery was associated with inefficient emotion regulation strategies (Santucci et al., 2008). Although the 2008 study mainly notes the relationship between vagal tone after a stressor and emotion regulation, it is important to consider the implications of how physiology may limit or support emotion regulation efforts and subsequent behavioral responses. For example, Beauchaine (2015) describes that reduced RSA and excessive RSA reactivity to challenges have been consistently observed among individuals with poor emotion regulation capabilities. This perspective takes into account the role of poorly regulated PNS responses, measured by RSA, across psychopathology. Additionally, it does not discuss the relationship between physiology and behavior but rather its relation to emotion regulation capacity. The repeated demonstration of vagal tone as a physiological indicator of an individual's ability to maneuver stressful situations serves as the basis for the usage of respiratory sinus arrhythmia in studies exploring emotion regulation.

The vagus is the tenth cranial nerve and promotes feedback between control centers in the brain and the target organs responsible for maintaining homeostasis; vagal tone refers to vagal control of the sinoatrial (S-A) node (Porges et al., 1994). When researchers investigate cardiac vagal tone, they are considering the vagus nerve's ability to mediate changes in heart rate through stimulation and withdrawal of the S-A node. This pathway is particularly important in the study of stress as the SNS and PNS responses increase and decrease heart rate, respectively. Porges and colleagues (1994) note that increases in heart rate are associated with reduced vagal action on the heart while decreases in heart rate are associated with increased vagal action. RSA is a useful measure when exploring vagal tone as it considers the changes in heart rate along with the breathing cycle.

Emotion regulation research continues to utilize RSA as an index of an individual's capability to manage their reaction to stressful stimuli. Studies suggest that a decrease in RSA in response to an emotional stimulus reflects more functional parasympathetic activity, meaning that children experiencing cardiac vagal withdrawal may be better able to manage stress (Gentzler et al., 2009). Children with higher resting RSA levels better produce the parasympathetic response, which may serve as a predictor of behavioral responses when faced with a stressor. Keeping in mind that appraisal of one's environment contributes to the physiological response, higher resting RSA levels represent a better capacity to confront emotional challenges by allowing more positive social behaviors to be exhibited.

Respiratory Sinus Arrhythmia as a Predictor of Behavior

Although parasympathetic activity during emotion regulation tasks is similar (i.e. the body attempts to return functions to baseline levels), how individuals outwardly regulate their emotions represents their ability to adapt to emotional challenges in a social context. Individuals with higher resting RSA, measured before the task, demonstrated more engaging coping (social-support seeking) compared to their lower resting RSA counterparts (Geisler et al., 2013). Although researchers considered a group of students ages 18-24 in the 2013 study, the self-reported habitual use of engagement coping strategies highlights the potential difference in behavioral responses to stress. Engagement coping in this study referred specifically to behaviors that confront the stressor such as situation control or social-support seeking. This finding precipitates our expectation that individuals with higher resting RSA would engage in more social problem-solving behaviors such as smiling, laughing, and approaching when faced with a stressful social situation, as these behaviors all aim to change the stressful social context by confronting rather than diverting attention away from the stressor.

One study asserted that children who demonstrated stable, high suppression of RSA from 2 to 4.5 years of age were less emotionally negative and exhibited fewer behavior problems and better social skills compared to those with unstable, low suppression of RSA in response to various lab challenges (Calkins & Keane, 2004). 154 two-year-old children participated in a series of intentionally challenging emotional and behavioral lab tasks examining baseline, attention, empathy, frustration, and problem-solving; 122 of the children were assessed again at the age of 4.5. Compared to previous descriptions of resting RSA, RSA suppression indicates the ability to which individuals produce a parasympathetic nervous system response (i.e. decreased heart rate and blood pressure) to a stressor. When participants in the 2004 study were exposed to a stressor, those with high suppression of RSA were observed demonstrating a biological response to the stressor that supports emotion regulation efforts. The relationship between social skills and RSA as an indicator of emotion regulation capacity builds upon the foundation created by experts looking into the stress response. Assuming children with lower RSA demonstrate a weaker ability to manage parasympathetic activity and thereby a lower capacity to regulate their emotions efficiently, this could translate to their ability to flourish in stressful social environments as their physiology works at a disadvantage compared to children with higher RSA.

Another study describes how children with lower baseline RSA scored lower on prosocial behavior before and after a behavioral challenge, however, RSA activity did not predict emotion regulation or prosocial behavior (Beauchaine et al., 2013). With this in mind, we can infer that individuals with higher resting RSA may be better equipped to handle stress physiologically and less likely to view social environments as hostile when presented with a stressful stimulus, resulting in a greater demonstration of social problem-solving behaviors. The way individuals appraise their experiences is critical to how they respond physiologically; in viewing their environment as less hostile and stressors as subsequently within their ability to cope, those with higher resting RSA may demonstrate different behaviors as a result of their appraisals.

In particular, as resting RSA increases, the social problem-solving behaviors examined in this study - expressed positive affect, laughter, speech, and approach - may appear more frequently in stressful social contexts. One study suggests that higher resting RSA is associated with trait positive affect as well as positive emotional expressivity, highlighting that this work is consistent with previous literature in its depiction of individuals with higher levels of resting RSA (Wang et al., 2013). The 2013 study suggests a relationship not only between resting RSA and positive affect but also establishes this behavior as a method of navigating stressful environments. While this sample focuses on college-aged participants, it is interesting that Wang and colleagues' findings are consistent with that of Geisler and colleagues' 2013 findings (mentioned earlier), in the sense that those with higher resting RSA exhibited certain behaviors in response to stressors. Furthermore, those with higher resting RSA (parasympathetic activity) may be able to more efficiently inhibit their sympathetic activation than those with lower resting RSA, resulting in behaviors such as engagement coping strategies and trait positive affect. In looking at additional social problem-solving behaviors (i.e. speech, laughter, approach), the current study aims to explore resting RSA as a predictor of these behaviors as a group in a stressful environment.

Although there are a variety of ways for individuals to self-regulate in stressful situations, social problem-solving behaviors are considered in this study to determine which children appraised the situation as a challenge they could manage rather than a threat they could not; social problem-solving behaviors demonstrate that the child either did not perceive the situation as overwhelmingly stressful or managed their stress well enough to response to the situation with functional, context-appropriate behaviors in an attempt to change the stressful situation. Social problem-solving refers to the way someone can gain more information or change a social situation that is unclear, unexpected, or stressful and is represented by expressed positive affect, speech, laughter, and approach. By engaging in these behaviors, individuals are taking an active role in facing a stressor and navigating an unfamiliar situation. More specifically, these behaviors are used in an attempt to solve a social problem. However, these behaviors do not exist in a vacuum; someone's physiological ability to manage stress should be a predictor of if they will be able to self-regulate well enough in the stressful context to demonstrate the functional behavior that will help change the situation.

Development During Childhood

We must also consider the developmental changes occurring in early and middle childhood in our discussion of emotion regulation capacity and social problem-solving behaviors. The PNS, while a mechanism of psychophysiology, also relies on cardiac maturation; whether this involves measures such as heart rate variability or respiratory sinus arrhythmia, the cardiac vagal tone tends to be used as an indicator of emotion regulation capacity. Therefore, cardiac maturation must be considered in our discussion of RSA as a measure of emotion regulation. While the cardiorespiratory system endures many changes from early to middle childhood, each measure of cardiac autonomic nervous system activity demonstrates different developmental trends. Harteveld and colleagues showed a sharp increase in RSA from 0.5 to 5 years of age and then a plateau, followed by a slight decrease around age 11 before stabilizing at the end of adolescence (Harteveld et al., 2021). Participants in our study, between the ages of 4 and 12 years of age, were thus in a pivotal though stable stage of cardiac maturation, which may have impacted the baseline RSA levels. While their physiology may have plateaued during the age range represented in our sample, children may experience cardiac maturation at different rates, leading to a sample with varying levels of cardiac development.

Early to middle childhood is also a developmentally interesting time in terms of social responding. One study describes how challenge appraisals increased across age groups from 3 to 11 years of age (Sillars & Davis, 2018). Children were asked to describe sad, scary, and anger-provoking experiences from their lives and to determine whether the event was something they could handle or whether it was too much. In identifying challenge and threat appraisals in the participants' lives, this study highlights how children's perceptions of stressors may evolve over the course of childhood. As it is noted that appraisal of one's environment may contribute to physiological and behavioral responses to stressful social contexts, this developmental shift contributes to our interest in social problem-solving behaviors in early to middle childhood.

Social information processing should also be considered in our discussion of appraisal. Social information processing describes how children process and interpret social cues in an environment and arrive at a decision, considering that children's appraisal of a situation influences their behaviors (Lemerise & Arsenio, 2000). To build upon this, children may take in additional information from their environment to assist them in determining whether they have the necessary resources to cope. It is furthermore interesting to consider how environment and perception contribute to the increase in challenge appraisals exhibited across age groups, as well as how this may impact the demonstration of social problem-solving behaviors when children may interpret social cues in a stressful social context differently.

The Current Study

Previous literature highlights not only that cardiac vagal tone is crucial to representing parasympathetic nervous system activity but also that respiratory sinus arrhythmia (RSA) serves as an index of trait emotion regulation capacity. By leaning on the physiological advantages that come with the PNS response, those with higher resting RSA are better equipped to face stressful social contexts and may thus be more likely to demonstrate certain behaviors and coping strategies. Social problem-solving behaviors, specifically, refer to a set of behaviors through which someone attempts to address and change a stressful situation. Considering the implications of trait emotion regulation capacity, we intend to focus on how RSA relates to social problem-solving behaviors in a stressful social context.

In the current study, we aim to explore the relationship between physiology and behavior in emotion regulation. To accomplish this aim, we plan to investigate how parasympathetic nervous system activity, measured by RSA, predicts social problem-solving behaviors in children faced with unfamiliar, stressful stimuli. By looking at the composite of social problem-solving behaviors (expressed positive affect, laughter, speech, and approach), we hope to illuminate how children's physiology predicts the manner in which they address a stressor.

How does resting respiratory sinus arrhythmia (RSA) relate to social problem-solving behaviors for children facing stressful situations? I expect that as resting RSA increases, the proportion of social problem-solving behaviors (expressed positive affect, laughter, speech, and approach) exhibited during the episode will increase.

Method

Participants

A total of 182 children between the ages of 4 and 12 (M = 7.73, SD = 2.304) participated in this lab study with a parent, between 2013 and 2015. The sample was composed of approximately even numbers of boys and girls (49.2% boys, 50.8% girls). The participants' backgrounds were racially and ethnically diverse with children's race and ethnicity reported as: Multi-racial (36.1%), Hispanic (30.1%), White (18.6%), African American (10.9%), Asian American (2.2%), and Other (2.2%). The sample was also economically diverse with annual family income reported as $30,000 or less (38.3%), $31,000 to $60,000 (32.5%), $61,000 to $90,000 (11.7%), or more than $91,000 (17.5%). These participants were recruited from the Inland Empire region in Southern California. Some participants (12) do not have resting RSA data because of technical difficulties with data acquisition. Thus,170 participants (M_{age} = 7.84 years, *SD* = 2.23; 50% boys) with complete physiological data were included in the current report.

Procedure

Children and parents arrived at the Emotion Regulation Lab and participated in the consent and assent process for a series of tasks. A researcher explained the study procedures to the parent and answered questions that arose, after which they secured parental informed consent for the child's participation and the child's assent. If the child was under 7 years of age, the researcher used only verbal assent and if the child was 7 years of age or older, they additionally provided written assent. The electrode placement occurred, and a cardiac baseline was collected towards the beginning of the visit. The Scary Mask task occurred about midway through their visit. At the end of the lab visit, the children watched a happy film. They were debriefed and compensated for their participation; parents received a $65 cash honorarium and children chose 1-2 prizes from a large prize box.

Psychophysiology Data Collection

Researchers placed seven disposable, pre-gelled electrodes over the child's torso to acquire the signal for the electrocardiograph (ECG) and impedance cardiograph (ZCG). Once the electrodes were placed correctly on the child's body and the leads were connected to the ambulatory acquisition device, the equipment was secured in a small backpack. Children provided a resting cardiac baseline for five minutes, during which they sat for two minutes, stood for one minute, and sat for the last two minutes. The electrodes remained attached to the child throughout the rest of the visit, however, only the baseline data was used in this study.

Scary Mask Episode

About midway through the lab visit, children entered a room where they unexpectedly encountered a female experimenter wearing a scary Halloween mask. The masked experimenter stood still, and then in 15-second intervals moved toward the participant, introduced herself as "Jamie," and eventually removed the mask. The episode concluded when the experimenter removed their mask. At this point, the experimenter would engage in an unstructured conversation with the child and indicate they were simply playing with the mask, resolving any issues that arose during the episode. Only the child's behavior during the portion of the episode when the mask was on was considered in the current study, not the recovery portion.

This situation would be stressful to a child as it represents a stressful social problem, where the experimenter is acting in a manner that is abnormal and unexpected. The adult in the room does not behave typically during this encounter; for example, they are wearing a scary mask and are unresponsive to the child. Thus, the child is faced with an unfamiliar situation and, without more cues to learn from, they must determine if the situation (i.e. the experimenter) is a challenge or a threat. The discomfort of the situation is furthermore something the child understandably would be motivated to change.

Behavior Coding

Each participant's video was coded in 10-second intervals, starting from the second the child first saw the masked experimenter. For each interval, researchers recorded the occurrence of four behaviors: expressed positive affect, laughter, speech, and approach. Behaviors were not considered to be mutually exclusive, meaning they could all potentially occur in every interval, and the coding for each interval is thus independent of all other intervals.

Expressed positive affect was operationalized as positive facial expressions, often characterized by an upturned mouth and raised eyebrows, similar to expressions that may be seen for emotions such as happiness, joy, or contentment. Speech was defined as any instance of intelligible spoken language from the child. Laughter ranged from full 'HA HA' out loud laughing to quiet giggles from the child, but there needed to be an audible sound produced for laughter to be coded. Approach was defined as movement toward the experimenter either with their full body, part of their body, or by leaning. The occurrence of each of these behaviors was recorded with a score of 0 (none), 1 (a little), or 2 (a lot) in each 10-second interval (Figure 1). Coders were extensively trained on these procedures and reliably coded the behaviors. Across the 4 behaviors included in this report, 20% of the cases were double-coded and interrater reliability for this subsample was 88% agreement. Social problem-solving behaviors in this study consisted of expressed positive affect, speech, laughter, and approach. The original interval codes were used to compute proportion scores (i.e. the proportion of the episode the child spent engaging in a specific behavior during the episode). After the videos were coded, the proportion of time children engaged in one behavior a little (1) and a lot (2) were collapsed to indicate that the child engaged in the behavior at all. The four observed behaviors were used as an index of social problem-solving as they proactively address a new, uncomfortable situation. The behaviors were translated into a proportion score sum and then z-scored in order to standardize the behavior in the episodes; in particular, z-scoring these sums indicated whether the child demonstrated more or less than the average amount of social problem-solving behaviors for the sample.

Results

These results are organized into two sections. First, I will present preliminary analyses of descriptive information including the mean and standard deviation of key variables, as well as the correlations between the study variables. In the second section, I report the analyses used to test my main hypothesis that as resting RSA increases, the proportion of social problem-solving behaviors exhibited during the episode will increase.

Preliminary Analyses

Tables 1 and 2 display the descriptive statistics and correlations among age, resting RSA, the social problem-solving composite, expressed positive affect, speech, laughter, and approach. Looking at the correlation between the behaviors, it is noted that several are co-occurring. For instance, expressed positive affect was significantly positively correlated with speech, $r = 0.270$, $p < 0.01$, and laughter, $r = 0.528$, $p < 0.01$. Speech also positively correlated with laughter, $r = 0.157$, $p = 0.041$, and approach, $r = 0.319$, $p < 0.01$. Thus, this supports our using these behaviors as a composite to investigate social problem-solving due to their strong correlations. Of note, age was positively correlated with the composite of social problem-solving behaviors, $r = 0.241$, $p < 0.01$. Thus, this supports our using this variable as a covariate in subsequent analyses due to its significant relationship.

How Does Resting RSA Relate to Social Problem-Solving Behaviors?

Table 3 displays the linear regressions we utilized to test our hypotheses. A linear regression was conducted in which resting RSA was entered as the predictor and the social problem-solving behavior composite was entered as the dependent variable, $F(1,168) = 3.795$, $p = 0.053$, $R^2 = 0.022$. A marginal effect between the resting RSA and social problem-solving behaviors was found ($b = 0.132$, $t = 1.948$, $p = 0.053$). This finding hints that there may be a relationship between resting RSA and social problem-solving behaviors, however, it is marginal.

To better understand the relationship between resting RSA and social problem-solving, we conducted a second exploratory analysis including age in the model. As mentioned earlier, age was positively correlated with the social problem-solving behaviors composite, prompting us to explore including it as a covariate in the test of the main hypothesis. Another linear regression was conducted in which resting RSA and age were entered as predictors and the social problem-solving behavior composite was entered as the dependent variable. This model revealed a significant effect of resting RSA ($b = 0.132$, $t = 1.974$, $p = 0.050$) in predicting social problem-solving behaviors when controlling for age ($b = 0.104$, $t = 3.165$, $p = 0.002$), $F(2,166) = 7.172$, $p = 0.001$, $R^2 = 0.80$. Both resting RSA and age were significant effects in this model. Here, covarying age helps to clarify the relationship; as age increases and as RSA increases, the proportion of social problem-solving behaviors demonstrated in the episode increases. When controlling for age (i.e. holding age constant), we also see an emergent significant relationship between RSA and social problem-solving behaviors.

Discussion

RSA and Social Problem-Solving Behaviors

This study aimed to investigate if RSA predicted social problem-solving behaviors in children faced with a stressful situation. There was a positive association between RSA and social problem-solving behaviors. In other words, as resting RSA increases, the proportion of social problem-solving behaviors (expressed positive affect, speech, laughter, and approach) demonstrated during the episode increased; however, this predicted effect only emerged as statistically significant when age was accounted for in the model. The relationship between these variables - RSA and social problem-solving behaviors as a whole - gives insight into the development of emotion regulation in children, both physiologically and behaviorally.

Beauchaine (2015) declared that reduced RSA is observed consistently among those with poor emotion regulation capacities, including those with various forms of internalizing and externalizing psychopathology as well as specific psychopathological syndromes. Acknowledging the role the PNS plays in emotion regulation efforts as well as encouraging methods such as social problem-solving behaviors in response to challenge appraisals may assist children in facing stressful social contexts in the future.

Age and Social Problem-Solving Behaviors

Another important variable in this study is age: older children were more likely to demonstrate social problem-solving behaviors than their younger counterparts. This may be a result of lived experience as older children have had more time and varying situations in which to practice social problem-solving behaviors. One study of kindergarten and first-grade boys showed that the older boys provided more effective solutions to hypothetical social dilemmas than the younger ones (Mayeux & Cillessen, 2003). Although participants were approximately 5 to 7 years of age, it is possible that the older children in this study have generally learned to confront challenges in a proactive way using social problem-solving behaviors rather than demonstrating alternative behaviors such as withdrawal. In future studies, it is worth considering if resting RSA is the main predictor of social problem-solving behaviors in this situation or if children's experiences are more impactful than physiology. For example, if their primary caretaker tends to utilize social problem-solving behaviors or alternative behaviors (e.g., expressed negative affect, withdrawal), children may be more likely to demonstrate those behaviors regardless of cardiac vagal tone.

In general, we understand there is a difference in approach to stressful situations based on age. Another reason for the association between age and social problem-solving behaviors may be due to more confidence in unfamiliar situations as opposed to simply more lived experience. Something scary or stressful for a 4-year-old child may not be as distressing for a 12-year-old child, for example. In the future, it may be worthwhile to look towards fear and/or aggression responses of children in response to stressful stimuli, especially considering how age contributes to any significant findings.

Limitations

Our physiological data specifically focused on the cardiac baseline (i.e. RSA) gathered before children engaged in the Scary Mask episode. As such, this study did not consider physiological data measured during the stressful social context itself (i.e. the time during which the child first sees the experimenter until the mask is removed) or after the episode ended (i.e. the time after which the experimenter took off their mask). Observing this data may clarify whether children's behavioral response is a result of them mobilizing resources or otherwise attempting to compensate for the stress of the event. The potential variation in RSA before (baseline), during (reactivity), and after the stressful social context may be worthwhile in investigating behavioral responses to stress.

It is also crucial to consider how a participant's appraisal of their environment impacts the way they respond to stress. As appraisal serves a large role in creating the stressful situation experienced by the participants, each participant may view and approach the stressor (i.e. the masked experimenter) differently based on their assessment of the situation as a challenge or a threat. With that being said, the current study did not directly consider children's tendencies to view situations as challenging or threatening. A previous study found that altered cardiac activity, specifically low parasympathetic activity, combined with an elevated cortisol awakening was associated with higher perceived stress (Rotenberg & McGrath, 2016). It would be interesting to consider in the future if the proportion of social problem-solving behaviors demonstrated in the episode would decrease as baseline RSA decreases, using perceived stress or anxiety as potential mediators.

Additionally, the current study only observed the relationship between RSA and social problem-solving behaviors in one stressful social context. In future studies, different laboratory tasks focusing on experiences such as frustration or sadness may better illuminate how the environment itself may influence both the physiological and behavioral response. By utilizing a myriad of tasks or assessments for participants to complete in pursuit of this line of study, future researchers may find a more well-rounded association between RSA and social problem-solving behaviors as it will address multiple types of emotional challenges.

Conclusions

We found that higher resting RSA was a predictor of social problem-solving behaviors and that age was a significant covariate in the current study, highlighting the significance of developmental psychophysiology. Measuring a child's ability to adapt to their environment and self-regulate through their parasympathetic nervous system response is critical to consider the long-term health implications of exposure to stress. In regard to PNS activity, individuals may face stressful situations at different starting points, however, their interpretation of the challenge may impact their biological response. This is not to say that those with lower resting RSA are fully constrained by the limits of their physiology, but rather that these individuals should consider other strategies to supplement their response to stress. With this in mind, it is important to note that what works for one individual to face stressful environments may not work for another. The effects of perception and appraisal on stress and subsequent emotion regulation should be considered in pursuing effective emotion regulation in the future. Interventions by parents, counselors, and educators to promote challenge appraisal and social problem-solving behaviors in response to challenging stimuli may be beneficial for future generations to successfully face unfamiliar, stressful situations.

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Figure 1

Scale for Behavior Coding

Behavior	0 (None)	1 (A Little)	2 (A Lot)
Face - Expressed Positive Affect	No Positive Facial Expression	Positive Facial Expression for Less than 5 seconds (up to 4.999 seconds)	Positive Facial Expressions for 5 Seconds or More
Utterance - Laughter	No Laughter	Laughter for Less than 5 seconds (up to 4.999 seconds)	Laughter for 5 Seconds or More
Utterance - Speech	No Speech	Speech for Less than 5 seconds (up to 4.999 seconds)	Speech for 5 Seconds or More
Proximity - Approach	No Approach	Partial Approach (Leans In, Reaches Toward)	Full Bodied Approach (Steps Toward Experimenter)

Table 1

Descriptive Statistics for Study Variables

Variable	*n*	*M*	*SD*
1. Age	169	7.836	2.277
2. Baseline RSA	170	6.377	1.126
3. SPS Composite	170	0	1
4. Expressed Positive Affect	170	0.709	0.374
5. Speech	170	0.509	0.333
6. Laughter	170	0.240	0.309
7. Approach	170	0.216	0.248

Note: Respiratory Sinus Arrhythmia (RSA), Social Problem-Solving (SPS).

Social Problem-Solving Behaviors Composite was z-scored.

Variables 4-7 describe the proportion of the episode the child engaged in the behavior.

Table 2

Correlations for Study Variables

Variable	1	2	3	4	5	6	7
1. Age		0.033	0.241**	0.361**	-0.06	0.250**	0.025
2. Baseline RSA			0.149	0.066	0.216**	0.15	0.192*
3. SPS Composite				0.825**	0.535**	0.701**	0.01
4. Expressed Positive Affect					0.270**	0.528**	0.098
5. Speech						0.157*	0.319**
6. Laughter							0.076
7. Approach							

Note: Respiratory Sinus Arrhythmia (RSA), Social Problem-Solving (SPS).

* $p < 0.05$, ** $p < 0.01$.

Table 3

Linear Regressions Examining Relation between RSA and Social Problem-Solving Behaviors

Model Summary

Model	R	R^2	Adjusted R^2
1	0.149[a]	0.022	0.016
2	0.282[b]	0.080	0.068

a. Predictors: Baseline RSA
b. Predictors: Baseline RSA, Age

ANOVA[a]

Model		Sum of Squares	*df*	Mean Square	*F*
1	Regression	3.733	1	3.733	3.795
	Residual	165.267	168	0.984	
	Total	169.000	169		
2	Regression	13.420	2	6.710	7.172
	Residual	155.311	166	0.936	
	Total	168.731	168		

a. Dependent Variable: SPS Composite
b. Predictors: Baseline RSA
c. Predictors: Baseline RSA, Age

Coefficients[a]

		Unstandardized	Coefficients	Standardized Coefficients	
Model		B	Std. Error		*t*
1	(Constant)	-0.842	0.439		-1.919
	Baseline RSA	0.132	0.068	0.149	1.948
2	(Constant)	-1.656	0.495		-3.344
	Baseline RSA	0.132	0.067	0.147	1.974
	Age	0.104	0.033	0.236	3.165

a. Dependent Variable: SPS Composite

Note: Respiratory Sinus Arrhythmia (RSA), Social Problem-Solving (SPS)