Respiratory Sinus Arrhythmia and Prosociality in Childhood: Evidence for a Quadratic Effect

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Abstract

Research investigating the links between the parasympathetic nervous system (PNS) and prosociality in children has yielded inconsistent findings. This relation has mainly been conceptualized as linear, however, the broader physiological literature suggests that children's physiological arousal and task performance may be related in an inverted U-shaped fashion—with peak performance at *moderate* levels of arousal. Therefore, we tested whether resting respiratory sinus arrhythmia (RSA)—a dispositional indicator of PNS activity—was quadratically related to child- and caregiver-reported sympathy and prosocial behaviors in an ethnically diverse sample of 4- and 8-year-olds (N = 300). We found a quadratic inverted-U shaped association between resting RSA and child-reported sympathy and prosocial behavior in 8-year-olds, whereas no consistent findings emerged for 4-year-olds. Therefore, moderate resting RSA in middle childhood may facilitate sympathy and prosocial behaviors. Dispositional over- or under-arousal of the PNS may impair children's ability to attend and respond to the distress of others by middle childhood.

Keywords: Respiratory sinus arrhythmia, parasympathetic nervous system, sympathy, prosocial behavior, children

Respiratory Sinus Arrhythmia and Prosociality in Childhood: Evidence for a Quadratic Effect

Prosociality, such as sharing and cooperation, is fundamental for peaceful and cohesive societies (Paolilli, 2011). There is evidence that the capacity for prosociality and its development are biologically based across species (Decety, Bartal, Uzefovsky, & Knafo-Noam, 2016). For example, in the Russian farm-fox experiment, researchers successfully increased foxes’ friendliness and social tolerance through generations of selective breeding, and this was accompanied by changes in the foxes’ autonomic nervous system functioning (Gogoleva, Volodin, Volodina, Kharlamova, & Trut, 2009). The autonomic nervous system also appears to play a role in the emergence and development of prosociality in humans, but the nature of this relation is still under investigation (Hastings & Miller, 2014). Porges and Furman (2011) theorize that the parasympathetic branch of the autonomic nervous system is particularly important for prosocial behaviors due to its influence on arousal in low threat situations (i.e., most social interactions). However, studies exploring this link have yielded inconsistent findings; researchers have found that relations between parasympathetic nervous system (PNS) activation and prosociality in children can be positive, negative, or not strongly related at all (Hastings & Miller, 2014). Empirical work on links between physiological arousal and other developmental outcomes, such as motor and cognitive task performance, has found that moderate physiological activation may be optimal (Arent & Landers, 2003; Marcovitch et al., 2010; Obradović, 2016). Thus, a possible explanation for the inconsistencies in the developmental literature is that the relation between PNS activity and prosociality is nonlinear.

The Parasympathetic Nervous System

The autonomic nervous system is comprised of two branches: the fight or flight (sympathetic) and the rest and digest (parasympathetic) systems (Porges & Furman, 2011). The sympathetic nervous system typically responds to threat, resulting in increases in heart rate, pupil dilation, and sweating, and supressed PNS functions (e.g., digestion), allowing more resources to be allocated to dealing with the threat at hand. Alternatively, the PNS comes online when the environment is less stressful and works to restore or maintain a sense of calm via the myelinated vagus nerve. Vagal activation can act as a "brake" on the heart, effectively lowering arousal and promoting homeostasis in the individual (Porges & Furman, 2011).

The PNS has been implicated in children's other-oriented, social-emotional capacities, such as sympathy and prosocial behaviors (Hastings & Miller, 2014; Malti, Sette, & Dys, 2016). A theorized anatomical route for the PNS's involvement in prosociality is the nucleus ambiguus, which is the point of origin for the myelinated vagus nerve. The nucleus ambiguus has other cranial nerves located either within or close by, which are involved in controlling facial expressions and vocalizations via the throat and larynx (Hastings & Miller, 2014). The close connection between the vagus and cranial nerves may allow mammals to downregulate their arousal through vagal activation, while also efficiently communicating that nonthreatening state to others, thus promoting social engagement (Porges & Furman, 2011). Resting levels of vagal activity are thought to reflect temperamental arousal and emotionality, while changes in vagal activity in response to environmental cues may be more indicative of situational attention focus, emotion regulation, and mood state (Beauchaine, 2001). Here we focus on resting vagal activity since we are interested in measuring dispositional prosociality.

Developmental researchers have assessed how vagal activity—measured via respiratory sinus arrhythmia (RSA)—develops and changes over the course of childhood. Across early childhood, resting RSA typically increases, although a small portion of children (< 10%) plateau during this time (Alkon, Boyce, Davis, & Eskenazi, 2011; Colasante, Peplak, Sette, & Malti, 2018; Patriquin, Lorenzi, Scarpa, & Bell, 2014). Children who plateaued in resting RSA from 2 to 4 years of age were rated as less socially responsive by their caregivers (Patriquin et al., 2014). By middle to late childhood, resting RSA either stabilizes or continues to increase depending on child-level characteristics (e.g., ethnicity; Hinnant et al., 2011; Marshall & Stevenson-Hinde, 1998). For instance, Hinnant and colleagues (2011) found that 9- and 10-year-old European American children showed increases in resting RSA over two years, whereas African American children started with higher RSA but showed no significant longitudinal change. While resting RSA appears to increase over childhood (particularly in early childhood), it remains unclear whether its relation to social-emotional responding becomes stronger (or weaker) over the same period. In this study, we aimed to shed light on these developmental differences by assessing links between resting RSA and core components of prosociality (i.e., sympathy and prosocial behavior; Malti et al., 2016) in early versus middle childhood.

RSA: Links with Sympathy and Prosocial Behaviors in Children

Sympathy is a feeling of sorrow or concern for another, which stems from the apprehension of another’s misfortune. Experiencing sympathy, however, does not necessarily mean the individual is sharing the same emotional state of another (Eisenberg, 2000). Sympathy orients the individual towards the needs of others, which can motivate prosocial behaviors (Eisenberg, Spinrad, & Knafo-Noam, 2015). Prosocial behaviors are voluntary actions that benefit another, such as helping and sharing, and are important because they have been shown to enhance cooperation, social engagement, and the formation of quality relationships (Chow, Ruhl, & Buhrmester, 2013; Eisenberg, Shea, Carlo, & Knight, 2014; Eisenberg et al., 2015; Markiewicz, Doyle, & Brendgen, 2001; Padilla-Walker & Christensen, 2011). Studying the biological mechanisms that underlie these prosocial capacities early in life is therefore crucial for understanding how they development (see Hastings, Miller, Kahle, & Zahn-Waxler, 2014; Knafo & Plomin, 2006).

In a nonthreatening environment, PNS activation is typically dominant, resulting in a stronger brake on heart rate. This lowers arousal, which allows for the communication of feelings of safety to others (Porges & Furman, 2011). From this perspective, higher resting RSA should be related to a higher propensity for other-oriented responses, such as sympathy and prosocial behaviors, and there is some evidence for this in children. Three-year-olds with higher resting RSA have shown greater sympathy 3 to 4 years later (Taylor, Eisenberg, & Spinrad, 2015). Similarly, higher resting RSA in 3- to 6-year-olds was associated with increased prosocial behaviors (Beauchaine et al., 2013; Clark, Skowron, Giuliano, & Fisher, 2016). However, other studies have documented null or even negative associations between resting RSA and prosociality in children (Hastings et al., 2014). For example, resting RSA in 2-year-olds was unrelated to empathic responses to another child crying (Gill & Calkins, 2003). Furthermore, Eisenberg and colleagues (1996) found that 8- to 12-year-old girls with higher prosocial reputations (peer-reported) actually had lower resting RSA (no significant relation for boys).

A possible explanation for these mixed results is that the resting RSA-prosociality relation does not fit the linear interpretation of previous studies. Instead, it may be similar to the story of Goldilocks and The Three Bears, such that too low or too high resting RSA is "no good", and moderate resting RSA is "just right". Children with low resting RSA may have a lower threshold for becoming distressed; when they are confronted with a distressed other, they may have more difficultly regulating their own vicariously induced distress (Miller, 2018). Significant distress draws attention away from the distressed other and toward themselves, impeding sympathy and corresponding prosocial behaviors (Eisenberg & Eggum, 2009). For example, 8- to 10-year-olds who showed greater heart rate deceleration and concerned facial expressions while watching a news report on an injured child in hospital were more likely to volunteer their recess time to help the injured child, whereas those with more distressed facial expressions were less likely to help (Eisenberg et al., 1989). Further, 8- to 12-year-old boys with disruptive behavioral disorders characterized by low emotional control and high anxiety, were found to have lower resting RSA and less deceleration in heart rate when viewing a sympathy-inducing film compared to controls (De Wied, Boxtel, Posthumus, Goudena, & Matthys, 2009). Thus, children with lower resting RSA may have more difficulty regulating their arousal, which could make it more challenging for them to maintain focus on others in need. Conversely, children with particularly high resting RSA may have a higher threshold for responding to aversive stimuli and thus lack sufficient physiological arousal to spur sympathy and helping behaviors (Miller, 2018; Miller et al., 2017).

In support of this quadratic approach to the resting RSA-prosociality link, Miller and colleagues (2017) found that children with moderate resting RSA had higher prosociality than those with lower and higher levels. They found this quadratic relation in three different studies of samples with varying levels of externalizing and internalizing problems. First, moderate resting RSA was associated with relatively higher prosociality (i.e., an aggregate of sympathy and prosocial behaviors) in 4- but not 6-year-olds with externalizing problems. Second, moderate resting RSA was associated with greater observed prosociality in response to the victim of a simulated accident and a higher proportion of shared tokens with a hypothetical sick child in a low-risk sample of 3- to 4-year-olds. Third, moderate resting RSA in a sample of 2- to 4-year-olds with internalizing symptoms predicted higher child- and mother-reported prosociality over five years later.

The Miller and colleagues (2017) studies provide initial evidence for a quadratic relation between resting RSA and prosociality in children. However, the conclusions that can be drawn from their study are limited by only concurrently assessing a single group of typically developing 3- to 4-year-olds. Further, this experiment used only lab-based behavioral tasks, which tend to reflect situation-specific prosociality and are generally inconsistently related with reports of dispositional prosociality (Holmgren, Eisenberg, & Fabes, 1998). Thus, these measures may be more related to contextual factors than being representative of a child's more general prosociality towards others. Miller and colleagues also used items measuring sympathy and prosocial behaviors in a single measure as a general assessment of prosociality. Although these constructs are related, they are also distinct in that sympathy is an emotion that orients children towards others, while prosocial behaviors are other-oriented actions that may or may not stem from sympathy. A child feeling bad for a needy other does not guarantee they will help them, nor is feeling bad for needy others an absolute prerequisite for prosocial behavior (Zuffianò, Colasante, Peplak, & Malti, 2015). Thus, we currently do not know if children's resting RSA is related to their prosocial emotions or behaviors, or both. Lastly, whereas previous developmental studies have documented ethnic differences in resting RSA (e.g., Hinnant et al., 2011), all three of the aforementioned studies utilized samples that were largely Caucasian.

The Present Study

This study was the first to test quadratic relations between resting RSA and two central dimensions of prosociality (i.e., dispositional sympathy and prosocial behaviors) in a large, ethnically diverse sample of typically developing children between distinct developmental periods (i.e., early versus middle childhood). Resting RSA increases significantly over the course of childhood indicating that the influence of the vagus nerve on prosociality may become more pronounced across this period (Hinnant et al., 2011; Porges & Furman, 2011). Therefore, we recruited 4- and 8-year-olds to investigate developmental differences in these relations. We also controlled for gender in all analyses due to reported gender differences in sympathy and prosocial behaviors in children (Malti, Gummerum, Keller, & Buchmann, 2009; Malti et al., 2016; Eisenberg et al., 2015). Based on existing findings (Marcovitch, et al., 2010; Miller et al., 2017), we hypothesized that moderate resting RSA in both 4- and 8-year-olds would be associated with higher sympathy and prosocial behaviors. Additionally, we expected these quadratic relations to be stronger in 8-year-olds because the baseline level of vagus nerve activity increases over the course of childhood.

Method

Participants

Participants were children ages 4- (*M* = 4.53, *SD* = .30, *n* = 150, 50% female) and 8-years-old (*M* = 8.52, *SD* = .27, *n* = 149, 50% female). Families were recruited from local community centers, events, and summer camps in an urban Canadian city as part of an ongoing longitudinal study of children's social-emotional development (data from this study was from the first wave). The sole exclusion criterion was the presence of an autism spectrum disorder. The sample was ethnically diverse and included the following ethnic backgrounds: 15% American, 15% South/Southeast Asian, 13% Western European, 9% East Asian, 5% Eastern European, 4% Central/South American, 3% West/Central Asian, 3% African, 1% Middle Eastern, 19% multi-ethnic, and 1% other; 12% missing/chose not to answer. All children and caregivers were fluent in English. The vast majority (92%) of caregivers received a postsecondary certificate, diploma, or degree, as compared to the 70% of 25- to 64-year-olds in the area's census data (Statistics

Canada, 2018). The sample's median household income was $80,000 to $125,000, which was similar to recent census data for the sampled city (Statistics Canada, 2018).

Procedure

The researchers' institution granted ethical approval. Oral assent was obtained from children and written informed consent was obtained from caregivers. Testers were undergraduate and graduate psychology students with extensive training on the physiological equipment and child interview techniques. Each child and their caregiver visited the laboratory for approximately 60 minutes. Children were outfitted with physiological equipment and assessed in a designated testing room while their caregiver remained in a nearby waiting area to complete a questionnaire on their child's social-emotional and prosocial development. After the assessments, caregivers were debriefed while children were given the opportunity to choose an age-appropriate book. The child assessments were recorded (video and audio) for data analytic purposes.

Measures

Resting RSA. Movement during physiological acquisition can cause artifacts in the data and children tend to have difficulties sitting still for the acquisition of resting physiology. It is typical for developmental researchers to use videos or stories to reduce children's movement. We therefore instructed children to remain still while they watched a 120-second video depicting a sea turtle slowly swimming in the ocean as we recorded their electrocardiogram (Gavin & Davies, 2007; for a comparison of a video baseline to traditional resting baselines, see Piferi, Kline, Younger, & Lawler, 2000). The experimenter left the room for the duration of the video. Three-lead electrocardiogram data were recorded at a sampling rate of 2 kHz using a Biopac MP150 data acquisition system and a BioNomadix module (Biopac Systems Inc, RRID:SCR_014829). Monitoring electrodes were secured slightly below the right clavicle and below the ribs on both sides. Leads from each electrode were connected to a module fastened around the midsection that communicated wirelessly via the MP150 with a computer in an adjacent room running AcqKnowledge 4.2 data acquisition software (AcqKnowledge Software, RRID:SCR_014279). Data were imported to Mindware HRV 3.0.21 (Mindware Technologies, Gahanna, OH, USA) for visual inspection, cleaning, and RSA calculation. They were cleaned in 10-second intervals to facilitate ease of processing. If more than 20% of an interval required editing, it was excluded from further analysis (n = 7). Other reasons for participant exclusion were refusal to wear physiological equipment (n = 15) and physiological equipment, computer, or video malfunctions during data collection (n = 16; final sample size with RSA data was N = 262). Resting RSA was computed as the mean level of RSA during the film (see Lewis, Furman, McCool, & Porges, 2012).

Sympathy. Caregivers completed a well-validated, five-item dispositional sympathy scale adapted from Eisenberg and colleagues (1996; e.g., "My child feels sorry for other children who are being teased"). Items were assessed on a 6-point scale (1 = *not at all* to 6 = *very much*; 4-year-olds α = .88, 8-year-olds α = .90). Children were asked to respond to the same five items (e.g., "I often feel sorry for other children who are sad or in trouble") on a 3-point scale (0 = *does not sound like me* to 2 = *really sounds like me*; 4-year-olds α = .72, 8-year-olds α = .77).

Prosocial behavior. Caregivers completed the widely used five-item dispositional prosocial behavior subscale from the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997; e.g., "shares readily with other children [e.g., treats, toys, pencils]"). Items were assessed on a 6-point scale (1 = *never* to 6 = *almost always*; 4-year-olds α = .81, 8-year-olds α = .83). Children responded to the same five items (e.g., "If someone is hurt, sad, or feeling sick, I help them") on a 3-point scale (0 = *does not sound like me* to 2 = *really sounds like me*; 4-year-olds α = .79, 8-year-olds α = .74).

Data Analytic Approach

We first ran descriptive statistics and correlations to explore relations between all study variables. Next, to test our quadratic hypotheses, we ran hierarchical multiple regressions with forced entry for each dependent variable: child-reported sympathy, caregiver-reported sympathy, child-reported prosocial behavior, and caregiver-reported prosocial behavior. Independent variables were age and resting RSA. Gender (1 = girl, 2 = boy) was added as a control variable. Independent variables were centered, while resting RSA was centered and then squared to create the quadratic resting RSA term (i.e., RSA^2). At step 1, gender was entered as a control variable alongside age. At step 2, resting RSA was entered to account for potential linear relations with sympathy and prosocial behaviors. Step 3 included the quadratic RSA term. To test our hypothesis on potential developmental differences, the interaction terms Resting RSA x Age and Resting RSA^2 x Age were entered at steps 4 and 5, respectively.

Results

Descriptive Statistics

The descriptive statistics of all study variables by age are shown in Table 1. Table 2 shows the correlations between all variables. Resting RSA, child- and caregiver-reported sympathy, and child- and caregiver-reported prosocial behaviors were all higher in 8- versus 4-year-olds. Thus, partial correlations controlling for age were performed. Controlling for age, girls reported higher prosocial behaviors than boys did, although child- and caregiver-reported sympathy and caregiver-reported prosocial behavior did not significantly vary by gender.

Further, resting RSA (linear term) was not significantly correlated with child- and caregiver-reported sympathy or child- and caregiver-reported prosocial behavior after controlling for age.

Resting RSA Links to Sympathy

We did not find any significant main effects of the linear or quadratic resting RSA terms on child- or caregiver-reported sympathy. There was, however, a significant interaction between the quadratic resting RSA term and age for child-reported sympathy (see Table 3). Specifically, there was no significant relation between the quadratic resting RSA term and child-reported sympathy in 4-year-olds. In 8-year-olds, however, we found a significant inverted-U-shaped relation between resting RSA and child-reported sympathy (see Figure 1 and supplementary Table 1). The interaction between the quadratic resting RSA term and age for caregiver-reported sympathy did not reach significance, however, the direction of the relation for 8-year-olds was consistent with child-reports (see Figure 2).

Resting RSA Links to Prosocial Behaviors

We found no significant main effects of the linear or quadratic resting RSA terms on reports of prosocial behaviors. There was, however, a significant interaction effect between quadratic resting RSA and age on child-reported prosocial behavior (see Table 4). There was a significant U-shaped relation between resting RSA and child-reported prosocial behavior in 4-year-olds. Similar to the results for sympathy, we found a significant inverted-U-shaped relation between resting RSA and child-reported prosocial behavior in 8-year-olds (see Figure 3 and supplementary Table 2). Caregiver reports of prosocial behavior showed consistent results with child-reports, however, the interaction effect between quadratic resting RSA and age was marginally significant (see Figure 4).

Discussion

The vagus nerve has been linked to the development of prosociality due to its proximity in origin to other cranial nerves that play crucial roles in responding to and communicating with others (Porges & Furman, 2011). Developmental researchers have recently proposed that relations between children's vagal activity and other-oriented, prosocial emotions and behaviors may be nonlinear; such that moderate resting vagal activity—rather than low or high—is associated with higher levels of prosociality (Miller, 2018; Miller et al., 2017). If this is the case, it suggests that children with lower resting vagal activity have more difficulty regulating their arousal, such that they may become over-physiologically aroused in the presence of a needy other, which could lead to greater focus on their own distress. In contrast, those with higher resting RSA may have a higher threshold for becoming physiologically aroused by distressing stimuli, impairing their ability to orient themselves to needy others. Those with moderate resting RSA may experience sufficient physiological arousal when witnessing needy others, but not so much that they are overwhelmed by their personal discomfort (Miller, 2018). Here we empirically tested this theorized Goldilocks effect. Our study was the first to separately test quadratic associations between resting RSA and dispositional measures of both sympathy and prosocial behavior in a large, ethnically diverse group of typically developing children in two distinct developmental periods. As such, we were able to generate new insight into how early and how consistently resting vagal activity is associated with prosociality in childhood.

Our results showed that resting RSA's relations to sympathy and prosocial behaviors was moderated by age. Specifically, 8-year-olds' resting RSA was quadratically related to their reported sympathy and prosocial behaviors, whereas resting RSA and child-reported sympathy and prosocial behaviors were not consistently related in 4-year-olds. For caregiver-reports, even though the interaction between age and resting RSA^2 was only marginally significant for reports of prosocial behaviors and not significant for reports of sympathy, both still showed results consistent with the child-reports for 8-year-olds. Resting RSA^2 explained similar amounts of variance for caregiver-reports of 8-year-olds as it did for the child-reported measures suggesting the inverted-U shape relation presents in the same direction consistently across measures for the 8-year-old cohort (see Figures 1, 2, 3, and 4). To summarize, moderate resting RSA was consistently associated with higher sympathy and prosocial behaviors in middle childhood, whereas the same relations were inconsistent between measures in early childhood. This suggests that moderate resting RSA is related to higher other-oriented emotions and behaviors in children, however, this relation may not be widely evident until sometime after early childhood.

Previous work has generally found that vagal activity increases over the course of childhood (Alkon et al., 2011; Colasante et al., 2018; Hinnant et al., 2011; Marshall & Stevenson-Hinde, 1998; Patriquin et al., 2014). During this developmental period, there is a parallel increase in children's ability to regulate their emotions, attention, and behaviors (Raffaelli, Crockett, & Shen, 2005). In early childhood, children have difficulty calming themselves down without the help of another (Kopp, 1989). By middle childhood, they become more independent and strategic in their emotional expression and regulation (Thompson, Lewis, & Calkins, 2008). Thus, increases in vagal activity may help children respond to their surroundings in a calm way, setting the stage for them to improve their emotional and behavioral regulation (Porges & Furman, 2011). At 4 years of age, the PNS may not be influential enough to be consistently implicated in emotional and behavioral tendencies—thus explaining 4-year-olds' relative lack of regulatory abilities. Furthermore, children's ability to attribute mental states—beliefs, intents, desires, etc.—to oneself and others, and to understand that others' mental states are different from one's own (i.e., theory of mind) are still nascent at this age (Wellman, Cross, & Watson, 2001; Wellman & Lagattuta, 2004). Thus, their perspective-taking skills are present but not well-developed yet, which may affect their motivations for caring for and helping others. Thus, 4-year-olds' combination of relatively lower levels of vagal activity and still developing social skills may explain why their resting RSA and other-oriented emotions and behaviors were not consistently related in the present study.

In terms of developmental differences, as expected, we found that 8-year-olds had higher resting RSA when compared to 4-year-olds. This suggests normative increases in resting RSA from early to middle childhood, which is largely consistent with previous findings (Alkon et al., 2011; Colasante et al., 2018; Patriquin et al., 2014). Supporting previous literature (Eisenberg et al., 2014), we found that child- and caregiver-reported sympathy and prosocial behavior are higher in middle versus early childhood.

Our results on resting RSA and prosociality in children supported some findings by Miller and colleagues (2017), but were inconsistent with some of their other findings. Broadly, our research supports that resting RSA is quadratically related to prosociality. However, in contrast to Miller and colleagues (2017), who found this association in a low-risk sample of 3- to 4-year-olds, we did not find consistent relations between resting RSA and prosociality in our sample of 4-year-olds but rather in 8-year-olds only. One potential explanation for these divergent findings is that the Miller and colleagues (2017) study used observed behavior in lab-based tasks to assess situation-specific prosociality in their low-risk sample of children. We used dispositional child and caregiver reports that asked how the child generally acts and feels, and the associations between state and dispositional measures can be weak in childhood (e.g., Zuffiano, Sette, Colasante, Buchmann, & Malti, 2018). This could indicate that the quadratic relation between prosociality and resting RSA can be found earlier in situational and/or observed measures, which may capture emerging traits in children. It is also possible that quadratic relations may be present in a sample of Caucasian 4-year-olds, but not in an ethnically diverse sample of 4-year-olds since resting RSA development may differ between ethnicities during childhood (Hinnant, et al., 2011). Lastly, how we acquired resting RSA could have influenced the results found. Four-year-olds may have found the video of the sea turtle swimming more engaging than 8-year-olds did, which could have contributed to their inconsistent findings. However, Miller and colleagues (2017) also used what they described as a "soothing video" for acquiring their resting RSA levels from 3- to 4-year-olds and did find a quadratic association between resting RSA and prosociality. They also found that watching a soothing video yielded similar RSA levels ($r > .85$) to sitting quietly or listening to soothing music (for 4- and 6-year-olds). The exact content of their videos was not specified, so it is still possible that differences between videos are driving differential results. Future research should attempt to discern which of these factors may be contributing to divergent results in early childhood and whether the influence of these factors remains stable into later childhood.

While this study generated new knowledge on the links between resting RSA and children's prosociality, it did have some limitations. First, we only assessed resting RSA (given our interest in dispositional prosociality), whereas other developmental researchers have found quadratic relations between RSA reactivity and performance on behavioral tasks. Marcovitch and colleagues (2010) found that 3.5-year-olds who showed moderate decreases in RSA during executive functioning tasks had increased performance compared to children who showed too little or too much RSA withdrawal. Secondly, this study used a cross-sectional, correlational design and thus does not allow for claims of causality. Thirdly, we relied on informant measures of prosociality, which is both a strength and limitation of the study. It is a strength because we were able to assess consistency across informants and (indirectly) measure children's prosociality across contexts (e.g., home and school). However, both caregivers' and children's reports may also be influenced by social desirability bias. To address this, future studies in this area should include teacher-reports and/or observed measures.

In conclusion, our results suggest that the relation between resting vagal activity and dispositional prosociality in childhood is more complex than a "more is always better" model. Instead, our results support a Goldilocks model in which an *optimal level* of vagal activity is located somewhere between the low and high ends of the spectrum, which only emerges consistently sometime after early childhood. These findings may be indicative of a larger pattern present in other areas of psychological research, which have yielded inconsistent relations between constructs of interest. For instance, both higher and lower levels of negative emotionality longitudinally predict higher levels of depression (Morris, Bylsma, & Rottenberg, 2009). These constructs may be related in a curvilinear manner that would otherwise be missed by linear models.

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Table 1

Descriptive Statistics by Age Group

	4-year-olds (n = 150)			8-year-olds (n = 149)		
	M	*SD*	Range	*M*	*SD*	Range
Resting RSA	6.52	1.19	3.66 – 9.30	7.06	1.10	4.18 – 9.72
Sympathy (child-reported)	.74	.57	0.00 – 2.00	1.56	.47	0.00 – 2.00
Sympathy (caregiver-reported)	4.16	1.21	1.20 – 6.00	4.81	1.05	1.00 – 6.00
Prosocial behavior (child-reported)	.97	.65	0.00 – 2.00	1.51	.43	0.00 – 2.00
Prosocial behavior (caregiver-reported)	4.38	.99	1.80 – 6.00	4.76	.95	2.20 – 6.00

Note. Child-reported scales ranged from 0 (does not sound like me) to 2 (really sounds like me) and caregiver-reported scales ranged from 1 (not at all or never) to 6 (very much or almost always).

Table 2

Zero-Order and Partial Correlations

Variable	1	2	3	4	5	6	7
1. Age	–	–	–	–	–	–	–
2. Gender	.00	–	.02	-.09	-.10	$-.16^{*}$	$-.12^{\dagger}$
3. Resting RSA	$.23^{***}$	.02	–	.10	.09	.08	.07
4. Sympathy (child-reported)	$.62^{***}$	-.05	$.22^{***}$	–	$.18^{**}$	$.73^{***}$	$.17^{**}$
5. Sympathy (caregiver-reported)	$.28^{***}$	$-.11^{*}$	$.12^{*}$	$.31^{***}$	–	$.21^{**}$	$.70^{***}$
6. Prosocial behavior (child-reported)	$.45^{***}$	$-.12^{*}$	$.17^{**}$	$.78^{***}$	$.28^{***}$	–	$.23^{***}$
7. Prosocial behavior (caregiver-reported)	$.20^{**}$	$-.16^{**}$	.10	$.24^{***}$	$.73^{***}$	$.28^{***}$	–

Note. Lower half = zero-order correlations. Upper half = partial correlations controlling for age. Gender (1 = girls, 2 = boys). RSA = Respiratory sinus arrhythmia. $^{\dagger}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 3

Hierarchical Multiple Regression for Resting RSA Relation To Children's Sympathy

	Child-Reported Sympathy					Caregiver-Reported Sympathy				
Variable	R^2	*B*	SE	ß	95% CI	R^2	*B*	SE	ß	95% CI
Step 1	.398***					.093***				
Gender		-0.09	.07	-.07	-0.22, 0.04		-0.27†	.14	-.12	-0.55, 0.00
Age		0.21***	.02	.63	0.18, 0.24		0.16***	.04	.28	0.10, 0.23
Step 2	.404†					.097				
Gender		-0.09	.06	-.07	-0.22, 0.04		-0.28*	.14	-.12	-0.55, 0.00
Age		0.20***	.02	.61	0.17, 0.23		0.16***	.04	.27	0.09, 0.23
RSA		0.05†	.03	.08	-0.01, 0.10		0.07	.06	.07	-0.06, 0.19
Step 3	.406					.105				
Gender		-0.09	.07	-.07	-0.22, 0.04		-0.27†	.14	-.12	-0.54, 0.00
Age		0.20***	.02	.61	0.17, 0.23		0.15***	.04	.26	0.08, 0.22
RSA		0.05†	.03	.08	-0.01, 0.10		0.06	.06	.06	-0.06, 0.18
RSA^2		-0.01	.02	-.04	-0.05, 0.02		-0.06	.04	-.09	-0.13, 0.02
Step 4	.409					.107				
Gender		-0.09	.07	-.07	-0.22, 0.04		-0.27†	.14	-.12	-0.54, 0.00
Age		0.20***	.02	.61	0.17, 0.23		0.15***	.04	.26	0.08, 0.22
RSA		0.05	.03	.08	-0.01, 0.10		0.07	.06	.07	-0.05, 0.19
RSA^2		-0.01	.02	-.02	-0.04, 0.03		-0.07†	.04	-.11	-0.15, 0.01
RSA x Age		-0.02	.02	-.06	-0.05, 0.01		0.02	.03	.04	-0.04, 0.09
Step 5	.420*					.112				
Gender		-0.10	.06	-.08	-0.26, 0.03		-0.28*	.14	-.12	-0.55, 0.00
Age		0.20***	.02	.60	0.17, 0.23		0.15***	.04	.25	0.08, 0.22
RSA		0.07*	.03	.12	0.01, 0.13		0.09	.07	.09	-0.04, 0.22
RSA^2		-0.01	.02	-.03	-0.05, 0.03		-0.07†	.04	-.12	-0.15, 0.01
RSA x Age		0.26*	.13	.90	0.01, 0.51		0.35	.28	.68	-0.20, 0.90
RSA^2 x Age		-0.02*	.01	-.96	-0.04, 0.00		-0.02	.02	-.64	-0.06, 0.02

Note. Child-reported (N = 254) and caregiver-reported (N = 261) sympathy. Resting RSA tested the linear relation, while resting RSA^2 was the quadratic relation. Girls were coded as 1 and boys were coded as 2 in analyses. RSA = Respiratory sinus arrhythmia. $^{\dagger}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 4

Hierarchical Multiple Regression for Resting RSA Relation To Children's Prosocial Behavior

	Child-Reported Prosocial Behavior					Caregiver-Reported Prosocial Behavior				
Predictors	R^2	*B*	SE	ß	95% CI	R^2	*B*	SE	ß	95% CI
Step 1	$.205^{***}$					$.051^{**}$				
Gender		-0.18^{*}	.07	-.15	-0.32, -0.05		-0.27^{*}	.12	-.14	-0.51, -0.04
Age		0.13^{***}	.02	.43	0.10, 0.17		0.09^{**}	.03	.18	0.03, 0.15
Step 2	.210					.054				
Gender		-0.18^{**}	.07	-.15	-0.32, -0.05		-0.28^{*}	.12	-.14	-0.51, -0.04
Age		0.13^{***}	.02	.41	0.09, 0.16		0.08^{*}	.03	.16	0.02, 0.14
RSA		0.04	.03	.07	-0.02, 0.10		0.05	.05	.06	-0.05, 0.15
Step 3	.211					.056				
Gender		-0.19^{**}	.07	-.15	-0.32, -0.05		-0.27^{*}	.12	-.14	-0.51, -0.04
Age		0.13^{***}	.02	.41	0.09, 0.16		0.08^{*}	.03	.16	0.02, 0.14
RSA		0.04	.03	.07	-0.02, 0.10		0.05	.05	.06	-0.05, 0.15
RSA^2		0.01	.02	.03	-0.03, 0.05		-0.02	.03	-.04	-0.09, 0.04
Step 4	.211					.056				
Gender		-0.19^{**}	.07	-.15	-0.32, -0.05		-0.27^{*}	.12	-.14	-0.51, -0.04
Age		0.13^{***}	.02	.41	0.09, 0.16		0.08^{*}	.03	.16	0.02, 0.14
RSA		0.04	.03	.07	-0.02, 0.10		0.05	.05	.06	-0.05, 0.15
RSA^2		0.01	.02	.03	-0.03, 0.05		-0.02	.03	-.04	-0.09, 0.05
RSA x Age		0.00	.02	-.01	-0.04, 0.03		-0.01	.03	-.01	-0.06, 0.05
Step 5	$.238^{**}$					$.067^{\dagger}$				
Gender		-0.20^{**}	.07	-.16	-0.33, -0.06		-0.28^{*}	.12	-.14	-0.52, -0.05
Age		0.12^{***}	.02	.40	0.09, 0.16		0.07^{*}	.03	.15	0.01, 0.14
RSA		0.07^{*}	.03	.13	0.01, 0.13		0.08	.06	.10	-0.03, 0.19
RSA^2		0.00	.02	.01	-0.04, 0.04		-0.03	.04	-.05	-0.10, 0.04
RSA x Age		0.40^{**}	.14	1.47	0.13, 0.67		0.39	.24	.91	-0.08, 0.86
RSA^2 x Age		-0.03^{**}	.01	-1.48	-0.05, -0.01		$-0.03^{\dagger}$	.02	-.92	-0.06, 0.01

Note. Child-reported (N = 254) and caregiver-reported (N = 261) prosocial behavior. Resting RSA tested the linear relation, while resting RSA^2 was the quadratic relation. Girls were coded as 1 and boys were coded as 2 in analyses. RSA = Respiratory sinus arrhythmia. $^{\dagger}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

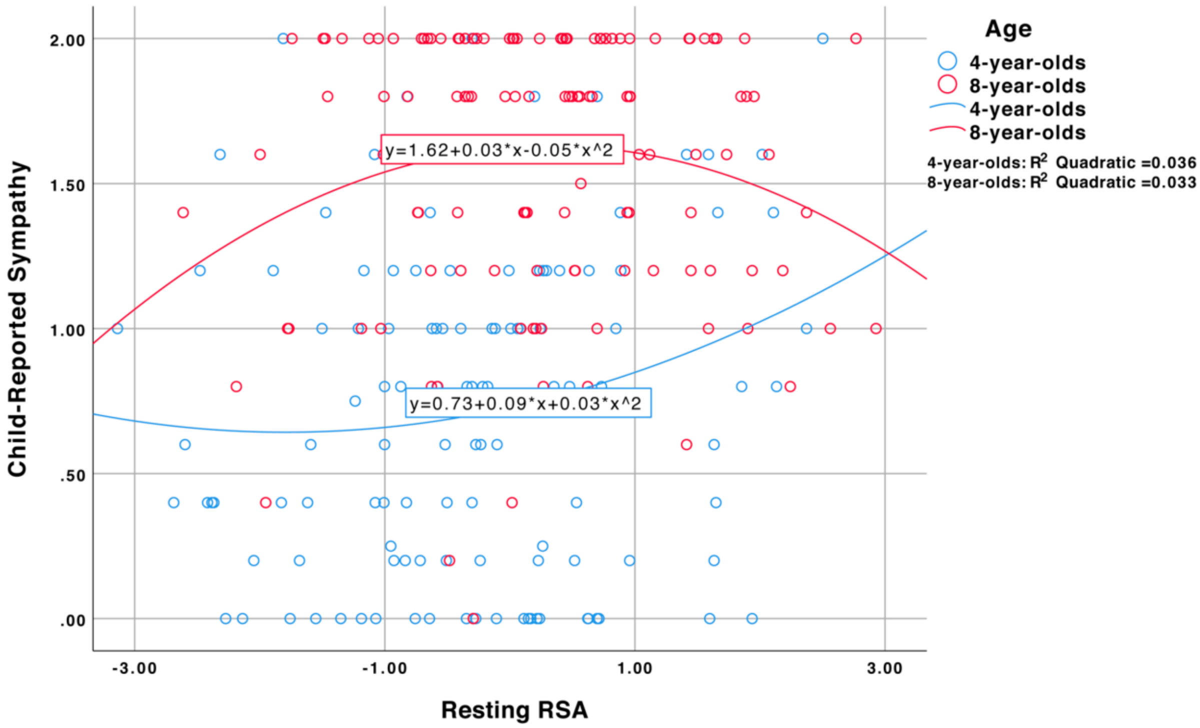

Figure 1. Scatterplot for resting RSA and child-reported sympathy in 4-and 8-year-olds. Resting RSA is mean centered. RSA = Respiratory sinus arrhythmia.

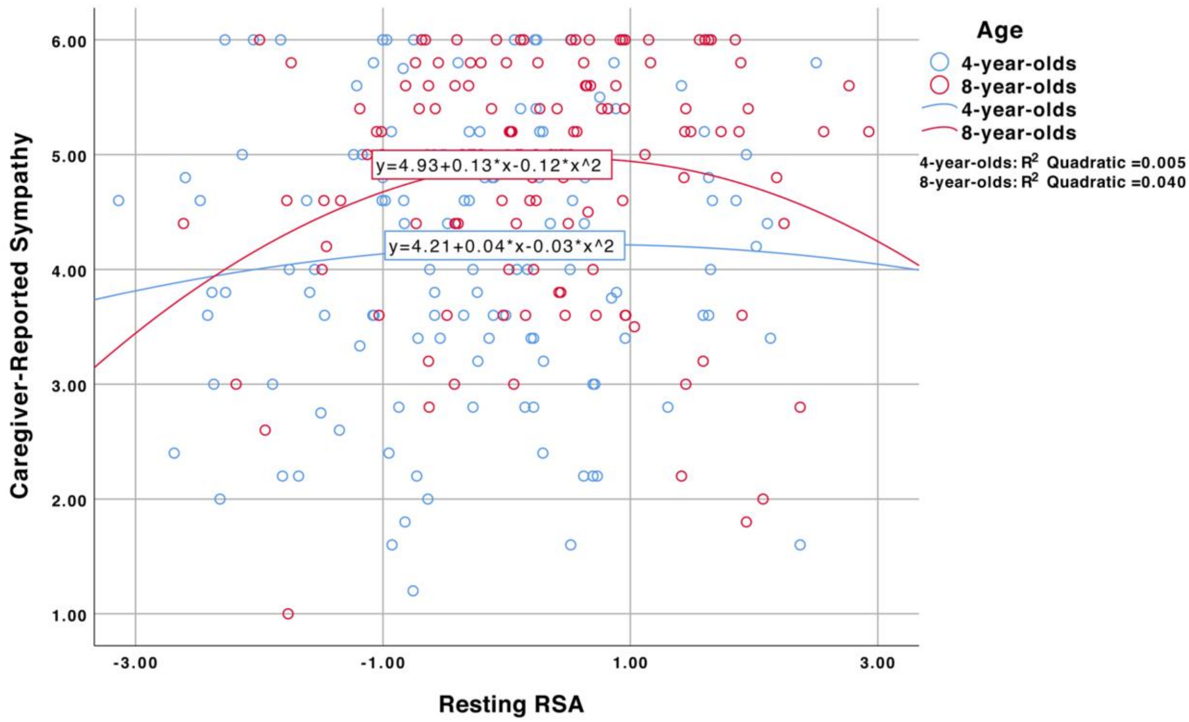

Figure 2. Scatterplot for resting RSA and caregiver-reported sympathy in 4-and 8-year-olds. Resting RSA is mean centered. RSA = Respiratory sinus arrhythmia.

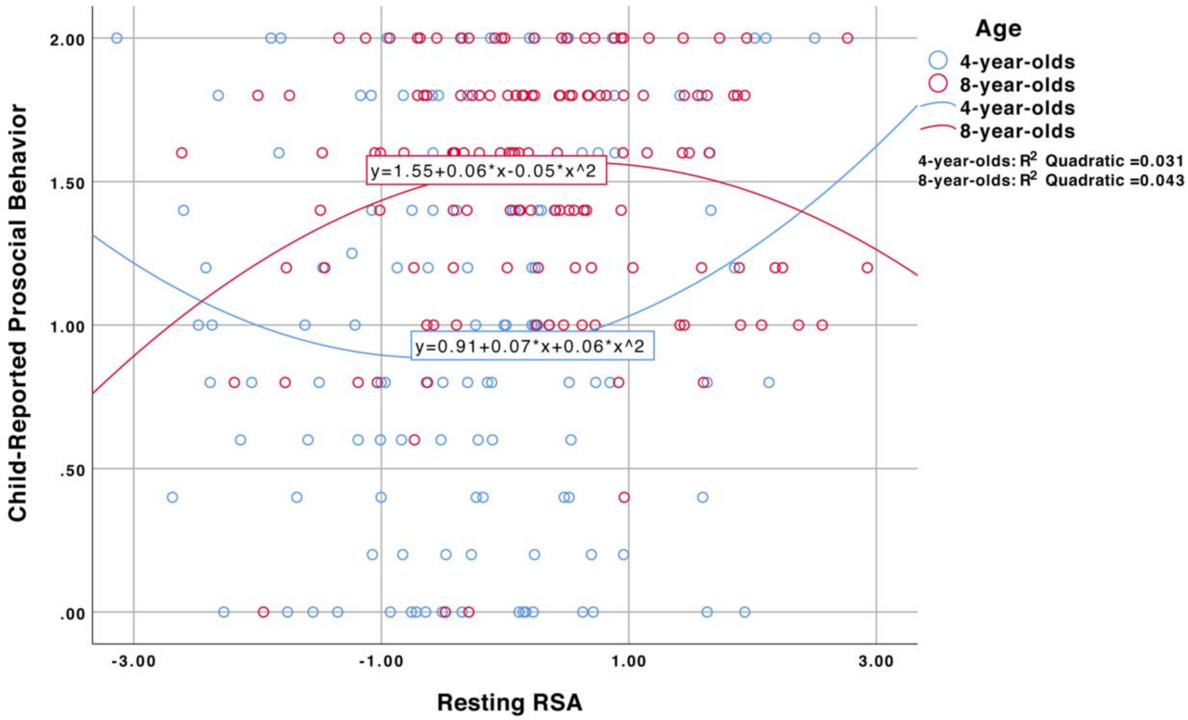

Figure 3. Scatterplot for resting RSA and child-reported prosocial behavior in 4-and 8-year-olds. Resting RSA is mean centered. RSA = Respiratory sinus arrhythmia.

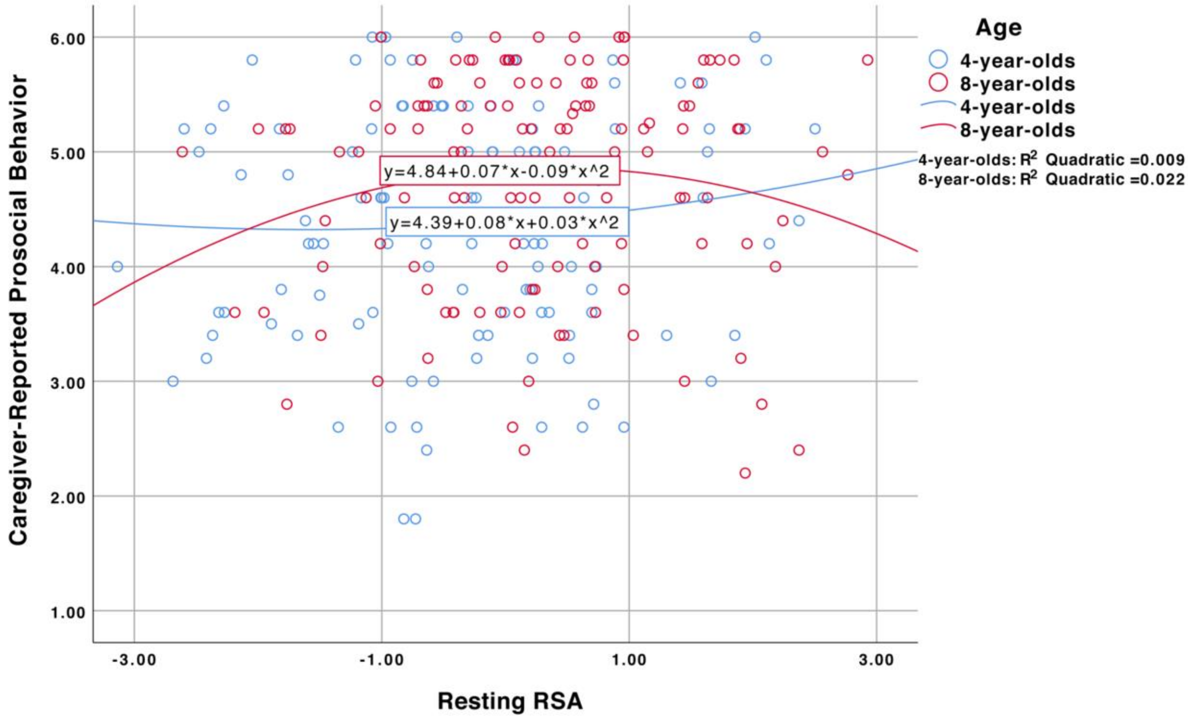

Figure 4. Scatterplot for resting RSA and caregiver-reported prosocial behavior in 4-and 8-year-olds. Resting RSA is mean centered. RSA = Respiratory sinus arrhythmia.