Cardiac Vagal Regulation and Early Peer Status[1]

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Graziano, P., Keane, S.P., & Calkins, S.D. (2007). Cardiac vagal regulation and early peer status. *Child Development*, 78, 264-278.

Abstract:

A sample of 341 5 ½ -year-old children participating in an ongoing longitudinal study was the focus of a study on the relation between cardiac vagal regulation and peer status. To assess cardiac vagal regulation, resting measures of respiratory sinus arrhythmia (RSA) and RSA change (suppression) to 3 cognitively and emotionally challenging tasks were derived. Results indicated that vagal regulation was positively associated with peer status. In addition, mediational analyses revealed that the relation between vagal regulation and peer status was mediated through better social skills for girls and better social skills and fewer behavior problems for boys. These findings are discussed in terms of the role of vagal regulation in the facilitation of children's positive social behavior.

Article:

Researchers have established that infants' abilities to regulate both positive and negative experiences are central to their socioemotional development (Kopp, 1989). Furthermore, throughout development, children's capacity to regulate emotions becomes increasingly complex and organized as they learn how to apply their knowledge about emotions to interpersonal exchanges (Denham et al., 2003; Fox, 1994; Shields & Cicchetti, 1997). Entrance to school marks a developmentally important period during which children experience increased interaction with unfamiliar people—peers and teachers—and begin to develop social relationships. Young children may have strong feelings in response to these changes and must regulate their emotions and express them in socially appropriate ways (Miller & Olson, 2000). Entrance to school, therefore, marks a significant and appropriate period to study the relation between emotion regulation and social competence, as measured by peer status, social skills, and behavior problems. Given the negative outcomes associated with peer rejection, such as early conduct problems, later adolescent disorders, school truancy, suspension, and school dropout (Coie, Lochman, Terry, & Hyman, 1992; Miller-Johnson, Coie, MaumaryGremaud, Bierman, & Conduct Problems Research Group, 2002; Woodward & Fergusson, 2000), it is important to investigate what individual factors contribute to social competence. A child's physiological ability to regulate emotions may be one factor that is important for successful social interactions.

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[1] This research was supported by National Institute of Mental Health awards (MH 55625 and MH 55584) to the third author and an NIMH award (MH 58144) to the second and third authors. The authors would like to thank Kathryn Degnan, Louise Berdan, David Topor, Rachael Reavis, and Caitlin Stone for their help in subject recruitment, data collection, and coding. The authors also thank the families who generously gave their time to participate in the study.

Research on the physiological substrates of emotion regulation—children's physiological differences in the ability to experience and modulate arousal—has focused primarily on the role of the sympathetic branch of the autonomic nervous system (ANS) by examining cortical reactivity in the facilitation of adaptive social behavior (Gunnar, Tout, de Haan, Pierce, & Stansbury, 1997; Gunnar, Sebanc, Tout, & Donzella, 2003). Only recently have researchers begun to look at the influence of the parasympathetic branch of the ANS on adaptive social behavior. Studying such influences is important because the parasympathetic branch modulates metabolic output from internal homeostasis demands to external or environmental demands. These environmental demands require internal processing that creates coping strategies aimed at controlling affective arousal (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). As appropriate emotion regulation has been linked to successful social behavior, an individual's ability to shift this metabolic output may be an important physiological marker for social competence.

Cardiac vagal tone—an index of the parasympathetic influence on the heart—has recently emerged as a psychophysiological marker for many aspects of behavioral functioning, including emotion regulation, in both children and adults. Assessing the functional output of the vagal pathways on the heart is accomplished by quantifying the amplitude of respiratory sinus arrhythmia (RSA), a component of heart rate variability. Research has indicated that RSA, under controlled respiratory conditions, is uninfluenced by variations in sympathetic activity, and provides a reasonable sensitive index of cardiac vagal tone, even when alterations in parasympathetic tone are small (Grossman, Stemmler, & Meinhardt, 1990). Porges' (1995) polyvagal theory introduces a model to explain the relation between vagal tone during steady states (i.e., baseline vagal tone) and vagal reactivity (i.e., the vagal ―brake" or vagal regulation) in response to environmental challenges. According to the polyvagal theory, baseline measures of vagal tone represent an organism's ability to maintain homeostasis and the potential responsiveness of that organism. As noted by Beauchaine (2001), high levels of baseline vagal tone have been associated with numerous factors, including uninhibited behavior, assertiveness, empathy, ability to deal with new situations, sociability, temperamental reactivity, reactivity to frustration, sustained attention, and social competence (Calkins, 1997; Eisenberg et al., 1995,1996; Fabes, Eisenberg, & Eisenbud,1993; Fox, 1989; Fox & Field, 1989; Stifter & Jain, 1996; Suess, Porges, & Plude, 1994). With an extensive and wide range of correlates, baseline vagal tone seems to be, at best, a broad measure of an individual's capacity to maintain a positive physiological state. Baseline vagal tone, however, does not index the actual regulation of arousal during stressful situations.

The vagal ―brake,'' on the other hand, does index the ability of the organism to regulate arousal by sustaining a shift in resources from a steady state to one with metabolic demands. Individual differences in regulation are assessed by measuring changes in vagal tone from baseline to an attention-demanding or challenging state. Vagal regulation can refer to a suppression in RSA during a challenging state (i.e., vagal tone decreases from baseline to a challenging task, indicative of a positive vagal regulation score) or to an augmentation in RSA (i.e., vagal tone increases from baseline to a challenging task, indicative of a negative vagal regulation score). According to polyvagal theory, however, successful vagal regulation is marked by RSA suppression, which is thought to facilitate an organism's ability to cope with challenging states by mediating metabolic output via heart rate increases. Porges and colleagues have conceptualized vagal regulation as a neurophysiological mechanism that enables the organism to modulate arousal by engaging and disengaging with the environment. Such strategies index an organism's ability to shift focus from a state of over- arousal to one of under-arousal to maintain physio logical homeostasis (Porges et al., 1996). Because social interactions require reciprocal engagement and disengagement strategies, vagal regulation may provide a more specific physiological marker for social competence. Additionally, as social interactions likely involve the experience of different levels of arousal and emotions, it is important to examine a regulatory physiological mechanism (i.e., vagal regulation) rather than simply examine one's resting physiological potential (i.e., baseline vagal tone) as past research has done (Eisenberg et al., 1995, 1996; Fabes et al., 1993).

Several studies have examined the role of vagal regulation in social development, with the initial evidence suggesting a positive relation. Despite a small sample, Porges et al. (1996) demonstrated that infants with vagal regulation difficulties during a social/attention task at 9 months of age had significantly more behavioral problems at 3 years of age. Calkins and Dedmon (2000) also found that 2-yearold toddlers with symptoms of externalizing problems displayed significant and consistent lower vagal regulation during the challenging situations than did children with no behavior problems. Vagal regulation has also been associated with children's behavioral regulation strategies during affect-eliciting situations (Calkins, 1997) and has been identified as a protective factor against externalizing problems associated with parental drinking and conflict (El- Sheikh, 2001; El-Sheikh, Harger, & Whitson, 2001).

Although several studies have assessed the relation between vagal regulation and children's positive social behavior, the findings are mixed. Cole, ZahnWaxler, Fox, Usher, and Welsh (1996) found no significant difference between the vagal regulation of expressive and nonexpressive groups. Blair and Peters (2003) found that vagal regulation was negatively related to teacher reported social competence but positively related to ontask behavior. Both studies were limited, however, by the use of only one brief mood induction story or mild cognitive task to obtain a vagal regulation measure. In addition, neither study controlled for children's initial baseline levels of vagal tone, which have been found to be moderately related to the magnitude of vagal regulation (Calkins & Keane, 2004; Doussard-Roosevelt, Montgomery, & Porges, 2003). Stifter and Corey (2001), on the other hand, found that infants with greater vagal regulation during a cognitive challenge task were rated by the experimenters as more social. Similarly, Calkins and Keane (2004) found that preschoolers with stable, high levels of vagal regulation were rated by mothers as having better social skills. Doussard-Roosevelt et al. (2003) found that greater vagal regulation was related to greater sociability as reported by mothers. Thus, there is partial support for the hypothesis that children who are better at regulating vagal tone have a greater capacity for social functioning.

There have not been any studies, however, that directly test the association between vagal regulation and social competence as measured by peer status. As peer rejection has been found to be related to several negative outcomes, it makes sense to directly examine its association with vagal regulation, rather than indirectly assess a child's social competence through teacher or mother reports. Additionally, to date, no study involving vagal regulation has included both teacher and peer reports of social competence. Examining multiple raters of social competence in the classroom may help to clarify the mixed findings in this area and determine how children’s physiological regulation relates to their behavior in the classroom, as well as how such behavior is perceived by peers and teachers. Moreover, few studies have examined the role of vagal regu- lation in school-aged children as most research has focused on toddlers or preschoolers. As entrance to school marks a time of increased social interactions and development of social relationships, it is important to examine the role of vagal regulation in older children’s social functioning.

The mechanism by which vagal regulation relates to social competence is also unclear as most research has focused primarily on its relation to negative social behavior (i.e., behavior problems). Do higher levels of vagal regulation relate to greater social competence by inhibiting impulsive, negative social behavior? Or does the modulation of arousal provided by the vagal ―brake” also facilitate the use of more advanced cognitive skills for social behavior such as better social skills?

Given prior research, the present study sought to examine the relation between vagal regulation and kindergarteners’ social competence, including peer status, social skills, and behavior problems. In addition, a unique aspect of the present study is that peer reports were used not only to assess children’s peer status but also to assess children’s behavior problems and social skills, as measured by peer nominations of shares and fights. Using peers as reporters of behavior problems and social skills provides us with a potentially useful way of assessing which social behavior elements young children take into account when assessing the overall like- ability of their peers (i.e., peer status). Assessing different social behavior elements (i.e., ―shares” and ―fights”) in the prediction of an overall likeability factor is especially important during kindergarten, which marks a period of increased social interactions for children. Thus, peer reports may provide unique information on children’s social competence skills when attempting to develop relationships. Finally, as peers are the ones who judge whether one is socially accepted or not, it is important to obtain their viewpoint on children’s social behavior.

The first question addressed in this study was whether vagal regulation is associated with peer status. Research on peer status indicates that socially competent children are more successful at regulating their emotions. For example, Eisenberg et al. (1993) found that boys with high emotional intensity and low regulation were more likely to have low socio- metric status. Based on this finding, we expected that vagal regulation would be positively associated with peer status.

The second and main question of this study was whether the relation between vagal regulation and peer status is mediated through behavior problems, social skills, or both. To examine this question, two sets of mediational analyses were conducted: one for behavior problems and one for social skills. To ensure that these two potential mediators function independently from one another, and as suggested when conducting multiple-regression analyses (Hair, Anderson, Tatham, & Black, 1998), we also tested them simultaneously in a single mediational model. Given previous findings linking greater vagal regulation to fewer behavior problems in infants (Porges et al., 1996), toddlers (Calkins & Dedmon, 2000), and children (El-Sheikh, 2001), as well as a finding suggesting a negative relation between negative affect and social skills (Eisenberg et al., 1993), we hypothesized that both behavior problems and social skills would mediate the relation between vagal regulation and peer status. Thus, we expected higher vagal regulation to predict lower behavior problems and better social skills, which would predict higher peer status.

METHOD

Participants

Participants for this study included three hundred and forty-one 5 ½ -year-old children (156 male, 185 female) obtained from three different cohorts participating in a larger ongoing longitudinal study. Four hundred and forty-seven participants were initially recruited at 2 years of age through child-care centers, the County Health Department, and the local Women, Infants, and Children program. In order to obtain a broad, community-based sample of children with a wide range of disruptive behavior, potential participants were screened using the externalizing subscale of the Child Behavior Checklist (CBCL 2–3; Achenbach, 1992). Further details about the recruitment may be found in Smith, Calkins, Keane, Anastopoulos, and Shelton (2004) and Calkins and Dedmon (2000). Of the original 447 participants, 365 participated at the 5-years-of-age assessment. The focus of the present study is on the 341 participants who came into the laboratory assessment at 5 ½ years of age and/or who were enrolled in schools granting permission for the school assessment during the kindergarten year. There were no significant differences in gender, socioeconomic status (SES), or 2-year externalizing T score between families who did and did not participate at the 5- years-of-age assessment.

The current study's sample of children (mean age = 68 months, SD = 3.2) was racially and economically diverse (67% European American; mean Hollingshead (1975) score = 43.2), and primarily from intact families (80%). Twenty-three percent of the children scored above the clinical or borderline range on externalizing behavior, 12% scored above the clinical or borderline clinical range on both externalizing and internalizing behavior, and 65% scored below the clinical or borderline range on both externalizing and internalizing behavior. Owing to the multiple assessments, sample sizes vary with 195 children (84 male) having complete data. There were no significant differences in gender, race, or SES between children with complete versus partial data.

Procedures

The focus of this study involved several assessments during the kindergarten year. The timeline of such assessments included a laboratory visit when children were approximately 5 ½ years of age, which was used to derive children's physiological regulation. The school assessment, which started in late October and ended in May of the kindergarten year, included teacher report of children's social and behavioral functioning, and a sociometric assessment of peer-reported behavior and peer status.

Sociometric Assessment and Nominations

Parents of the participating children, who attended a school where the principal approved the project, consented to have their child participate in a sociometric assessment in his or her classroom. Sociometric interviews began in October during the kindergarten year to allow time for classmates to become familiar with each other (Coie, Dodge, & Coppotelli,1982; Keane & Calkins, 2004). A modified version of Coie et al's. (1982) original procedure was used. Trained graduate students individually interviewed each child for whom parental consent was granted.

Pictures were used as prompts during the interview to aid in gathering reliable peer report data with kindergarten children. To increase the stability of measurement for the sociometric nominations, cross-gender nominations were permitted (Terry & Coie, 1991).

The modification to the Coie et al.'s (1982) procedure was as follows: Children were asked to provide unlimited nominations of peers they ―liked most" and ―liked least" (Terry, 2000). This procedure reduces measurement error and allows for reliable assessments of sociometric status with fewer classmates than what is required by the standard limited- choice sociometric procedure. In addition, using a procedure from Keane and Calkins (2004), children were asked to nominate classmates for behavioral categories including ―starts fights" and ―shares." For the purpose of this study, nominations for ―like most" and ―like least" were used to determine peer status, peer nomination for ―fights" was used as the peer report of behavior problems, and peer nomination for ―shares" was used as the peer report for social skills. Given the young age of the participants, children were trained on sample items until they understood the task, and sociometric interviewers were rigorously trained to ensure quality data collection. Scripts detailing several specific examples of the behaviors of interest were provided to explain these constructs to children who were confused or having difficulty.

Laboratory Assessment

Mothers accompanied their child to the laboratory where the child was assessed using several procedures in a laboratory playroom. First, the experimenter placed three disposable pediatric electrodes in an inverted triangle pattern on the child's chest while the mother was seated at a table next to the mother. The electrodes were connected to a preamplifier, the output of which was transmitted to a vagal tone monitor (VTM-I, Delta Biometrics Inc., Bethesda, MD) for R-wave detection. The vagal tone monitor displayed ongoing heart rate (HR) and computed and displayed an estimate of RSA (vagal tone) every 30 s. A data file containing the interbeat intervals (IBIs) for the entire period of collection was transferred to a laptop computer for later artifact editing (resulting from child movement) and analysis. The onset and end of each challenge episode was marked on the computer file of the IBI data through the use of an electronic signal controlled by the experimenter. While connected to the HR collection equipment, the child was observed during a multi- episode sequence derived from the Laboratory Temperament Assessment Battery (LAB-TAB; Goldsmith & Rothbart, 1993) and methods used in prior work (Calkins, 1997; Calkins & Keane, 2004; Kochanska, Murray & Coy, 1997).

The baseline episode consisted of a 5-min segment of the videotape ―Spot,'' a short story about a puppy exploring a neighborhood. Although this episode was not a true baseline measure as the child's attention was engaged in an external stimulus, it was able to keep the child sitting quietly and displaying little affect. Given the age of the children, such a stimulus was necessary to keep the child seated at the table and to limit movement artifact in the HR data. Following the baseline episode, the child was observed in several situations designed to elicit physiological stress and coping. Of interest to the present study are the cognitive tasks that have been shown to yield the greatest vagal suppression (Calkins & Dedmon, 2000; Stifter & Corey, 2001). The first cognitive task was a 4-min problem-solving task, during which the child attempted to solve a difficult puzzle. The next task was a 4-min effortful control task similar to a Stroop task. The child was presented with large pictures representing large shapes (animals, geometric figures). Within the larger pictures, smaller shapes were depicted. In half of the trials the small shapes were consistent with the large shape (e.g., a large cat was made up of identical smaller cats), and in the other half the shapes were inconsistent (e.g., large circle made up of small squares). The child was asked to identify only the smaller shapes in the pictures presented and were instructed to answer as fast as they could. The last episode was a 3-min attentional persistence task, during which the child was asked to sort a large number of beads by color and place them in a container (LAB-TAB; Goldsmith & Rothbart, 1993).

Each challenge episode was separated from the subsequent episode by a very brief (2–3 min) period during which the child was free to interact with the mother while the experimenter gathered materials for the next episode. This period was necessary because the children's tolerance for the heart rate collection (and in particular, remaining seated for collection) was often low. This break was not considered to be an additional resting measure of cardiac activity with which to contrast the subsequent challenge episode, given that the child was almost always engaged with the mother or was moving around (or both). Moreover, there was some concern that there would be carry-over effects from the episode to the break that would call into question the validity of using the break to derive resting measures. For these reasons, only the initial baseline measure was considered for analyses involving contrasts with the challenge episodes.

Measures

Social skills. To assess the children's social skills, teachers completed the kindergarten version of the Social Skills Rating System (SSRS; Gresham & Elliot, 1990). The SSRS is a 30-item behavior rating scale designed to assess children's social behavior. The form lists a variety of social behaviors; raters indicate the frequency with which the child engages in each behavior (0 = never, 1 = sometimes, 2 = very often) and how important each of these behaviors is for the child's development (0 = not important, 1 = important, 2 = critical). A social skill raw score is derived from these items along with three subscales (Cooperation, Assertion, Self-Control). The SSRS has well-established internal consistency (ocs range from .78 to .95), reliability (test–retest reliability correlations range from .75 to .93), and criterion-related validity with the CBCL (Gresham & Elliot, 1990). The present study used the total social skill raw score.

Behavior problems. To assess the children's behavior problems, teachers completed the elementary school version of the Behavior Assessment System for Children (BASC; Reynolds & Kamphaus, 1992). The BASC is a widely used behavior checklist that taps emotional and behavioral domains of children's functioning. The teacher elementary school version used for children ages 212–5 contains 109 items whereas the version used for children ages 6–11 contains 148 items. Because some of the children in our sample turned 6 during the kindergarten year, it was necessary to give them the ages 6 –11 version of the BASC. Each item on the BASC is rated on a 4-point scale with respect to the frequency of occurrence (never, sometimes, often, and almost always). The measure yields scores on broad internalizing, externalizing, and behavior symptom domains as well as nine specific content scales. The BASC has well-established internal consistency, reliability, and validity (Doyle, Ostrander, Skare, Crosby, & August, 1997; Reynolds & Kamphaus, 1992). For the purpose of the present study, the general externalizing T score was examined.

Sociometric measures. The total number of peer nominations each child received was calculated and standardized within each classroom in order to derive z scores representing the number of

―like least” and ―like most” nominations. The standardized ―like least” nominations were subtracted from the standardized ―like most nominations,’’ and then restandardized to generate a Social Preference Index (Coie et al., 1982). This procedure is the accepted form of establishing a child’s overall likeability within the classroom. As social preference scores decrease, a child’s likeability or overall peer status also decreases. The standardized social preference score was used as the dependent variable in this study. In addition, z scores for the additional behavioral categories (―fights” and ―shares”) are computed to provide peer-reported indexes of social behavior for all target children. Both of these behavioral nominations have been shown to have adequate reliability and validity when compared with teacher reports of the same constructs (Coie et al., 1982; Ladd & Mars, 1986). All three sociometric measures were normally distributed with an adequate range of z scores (social preference range = — 2.48 to 2.16; ―fights”= —1.81 to 2.92; and ―shares”= —1.89 to 2.22), suggesting that there was sufficient variability in the behavior of participants in this sample.

Physiological measures. To generate measures of cardiac activity from which to derive measures of resting RSA (baseline vagal tone) and RSA suppression (baseline vagal tone — challenge vagal
tone = vagal regulation), the IBI files were edited and analyzed using MXEDIT software (Delta Biometrics, Bethesda, MD). Editing the files consisted of scanning the data for outlier points relative to adjacent data, and replacing those points by dividing them or summing them so that they would be consistent with the surrounding data. Data files that required editing of more than 5% of the data (12 data points in a 5-min period for example) were not included in the analyses (n = 13).

Estimates of RSA were calculated using Porges’ (1985) method to analyze the IBI data. This method applies an algorithm to the sequential heart period (HP) data. The algorithm uses a moving 21-point polynomial to detrend periodicities in HP slower than RSA. A band-pass filter then extracts the variance of HP within the frequency band of spontaneous respiration in young children: 0.24 –1.04 Hz. Although lower frequency bands may be studied, research with young children has consistently examined this band and identified associations with child functioning (Huffman et al., 1998; Porges et al., 1996; Stifter & Fox, 1990). The estimate of RSA was derived by calculating the natural log of this variance and is reported in units of ln(ms)^2. RSA was calculated every 30 s for the 5-min baseline period and all other challenge episodes > 3 min in length. The mean estimate of RSA of the 30-s epochs within each episode was used in subsequent analyses. If the standard deviation across the epochs was greater than 1.00 for RSA (indicating a high degree of variability over the course of the episode and calling into question the validity of the mean RSA value), that episode was excluded from subsequent analyses (n = 3). Descriptive statistics for RSA for the baseline and challenge episodes are reported in Table 1. No significant gender, racial, or SES differences emerged in relation to any of these physiological measures.

As the table indicates, the data files of several children were not included in some of the analyses. Several situations led to missing data across the three tasks. A few children would not allow the experimenter to apply the HR electrodes (n = 4). In other situations, the HR data collection equipment failed on several occasions (n = 21). A third cause for missing data was that the child pulled on, or touched, the HR leads at the beginning of the collection procedure, which caused excessive movement artifact affecting greater than 5% of the data in the HR file, thus not allowing appropriate editing (n =13). Multivariate analyses indicated no differences in descriptive measures between children with complete HR data and those with missing data.

Vagal regulation scores indexed by change scores were computed for each challenge episode by subtracting the challenge episode RSA from the baseline RSA. These change scores are also indicated in Table 1. Consistent with previous research methodology

Table 1
Descriptive Statistics for RSA and RSA change

	M	*SD*	Minimum	Maximum	*N*
RSA					
Baseline RSA	6.09	1.15	3.28	9.42	297
Problem solving RSA	5.49	1.10	2.34	9.00	293
Effortful control RSA	5.88	1.17	3.01	8.80	290
Attentional persistence RSA	5.57	1.13	2.72	8.85	286
RSA change					
Problem solving	0.59[a]	0.70	−2.38	3.23	293
Effortful control	0.20[a]	0.72	−2.08	2.28	290
Attentional persistence	0.49[a]	0.74	−1.77	3.24	286

Note. RSA = respiratory sinus arrhythmia.
[a]Positive change scores indicate a decrease in RSA from baseline to task (i.e., RSA suppression or a positive vagal regulation score).

Table 2
Descriptive Statistics for Study Variables for Boys and Girls

	Boys			Girls		
	M	*SD*	*N*	*M*	*SD*	*N*
Peer						
"Fights"	0.50	1.03	113	−0.38	0.70	138*
"Shares"	−0.32	0.94	113	0.28	0.95	138*
Social preference	−0.17	0.99	113	0.06	0.93	138+
Teacher						
Social skills (SSRS)						
Social skills raw score	40.93	9.77	121	44.13	9.47	147*
Behavior problems (BASC)						
Externalizing general *T* score	49.96	10.40	115	45.91	8.26	143*

Note. BASC = Behavior Assessment System for Children; SSRS = Social Skills Rating System.
*Significant gender difference at $p < .05$.
+Significant gender difference at $p < .06$.

(Blair & Peters, 2003; Calkins & Keane, 2004; Porges et al., 1996), positive change scores indicate a decrease in RSA from baseline to task (i.e., RSA suppression or a positive vagal regulation score). At this time, the physiological data were also examined for any outliers defined as data points 3 or more standard deviations away from the mean. One outlier was found and excluded from the data set.

RESULTS

Data Reduction

Given the several tasks involved during the physiological assessment, a reduction in the number of challenge episodes was necessary. Owing to moderately high correlations between the vagal regulation scores (ranging from r =.56 to .76, p<.001), the three vagal regulation scores were averaged to obtain an overall vagal regulation composite score.

Preliminary Analysis

Given the different reporters and the varying procedures for data collection (laboratory and school assessment), the number of participants varied between assessments. Sample sizes for all outcome measures are reported along with the descriptives in Table 2. Each separate analysis used all available data. In addition, one data point was excluded from the data set as one teacher filled out the questionnaires incorrectly. Preliminary multivariate analyses found a positive relation between vagal regulation and baseline vagal tone, r 5.39, p <.001. Given the present study's focus on vagal regulation, baseline vagal tone was controlled for during all analyses.

Additional preliminary multivariate analyses with all outcome variables revealed several gender differences. The means for boys and girls across all study measures are also presented in Table 2. As the table indicates peers were more likely to nominate boys as ―fights" and girls as someone who ―shares." Girls also obtained significantly higher social preference scores than boys. Teachers reported girls as having significantly better social skills and less externalizing problems than boys. Owing to these findings, gender was examined as a possible moderator via an interaction term. No significant relations between the measures of SES and race and the study's outcome measures were found and thus were not considered in subsequent analyses.

Vagal Regulation and Social Preference

The first goal of this study was to examine the relation between vagal regulation and peer status. It was hypothesized that vagal regulation would be associated with higher social preference scores. To address this research question, regression analyses were conducted. To control for baseline vagal tone, it was entered first into the regression. The main effects of gender and vagal regulation were entered in the second step. Next, the interaction between gender and vagal regulation was entered to assess gender as a possible moderator. The dependent variable for the regression analysis was social preference, derived from peer reports. After controlling for baseline vagal tone, only the main effect for vagal regulation

Table 3
Correlations Between Variables of Interest

Variable	1	2[a]	3	4	5	6	7
1. Baseline RSA	–						
2. Vagal regulation	.39***	–					
3. Social preference	.02	.15*	–				
4. "Shares"	– .06	.16*	.63***	–			
5. "Fights"	.02	– .10	– .46***	– .44***	–		
6. Externalizing general *T* score	.10	– .08	– .36***	– .32***	.41***	–	
7. Social skills raw score	– .10	.15*	.37***	.33***	– .35***	– .66***	–

Note. RSA = respiratory sinus arrhythmia; Vagal regulation = average RSA suppression across three cognitive tasks.
[a]Controlled for baseline RSA.
*$p<.05$, **$p<.01$, ***$p<.001$.

was a significant predictor of social preference, total R^2 =.03, $R^2\Delta$ =.03, $F(2,208) = 3.19$, $p<.05$, β =.17. Thus, children who showed greater RSA suppression during the cognitive tasks, indicative of positive vagal regulation scores, were more likely to obtain higher social preference scores. There were no significant effects of baseline vagal tone, gender, or a Gender x Vagal regulation interaction for social preference.

What Mediates the Relation Between Vagal Regulation and Social Preference?

Owing to the significant finding between vagal regulation and social preference, analyses were conducted to examine whether social skills, behavior problems, or both mediated the effects of vagal regulation on social preference. To test mediation, procedures recommended by Baron and Kenny (1986) were followed. First, the independent variable must predict the mediator. Second, the independent variable must predict the dependent variable. Third, the mediator must predict the dependent variable. Perfect mediation holds if the independent variable has no significant effect on the dependent variable when the mediator is controlled.

First, the relations between vagal regulation and the potential mediators (behavior problems and social skills) were examined via regression analyses. It was hypothesized that vagal regulation would be related to fewer behavior problems and better social skills as reported by both teachers and peers. Once again baseline vagal tone was entered first in the regressions, followed by the main effects of gender and vagal regulation, and lastly the Gender x Vagal regulation interaction term.

First, as depicted in Table 4, vagal regulation did not predict peer report of behavior problems, after controlling for baseline vagal tone. There was, however, a main effect for gender, with boys being significantly more likely to be nominated as someone who ―fights" compared with girls. There was no

Table 4
Regression Analyses Testing Vagal Regulation as a Predictor of Behavior Problems

		β	R^2	R^2 change	F change
Predictors of teacher report of behavior problems ($n = 214$)					
Step 1.	Baseline vagal tone	.12	.01	.01	2.22
Step 2.	Gender	$-.45^{*}$	.05	.04	4.92^{**}
	Vagal regulation	$-.27^{**}$			
Step 3.	Gender × Vagal regulation	$.39^{+}$	.07	.02	2.90^{+}
Predictors of peer nominations of "fights" ($n = 211$)					
Step 1.	Baseline vagal tone	.03	.00	.00	0.10
Step 2.	Gender	$-.46^{***}$	.19	.19	24.45^{***}
	Vagal regulation	$-.25$			
Step 3.	Gender × Vagal regulation	.17	.19	.00	0.72

Note. $^{+}p<.09$, $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

significant effect for a Gender x Vagal regulation interaction for the prediction of peer nomination of someone who ―fights." On the other hand, in terms of predicting behavior problems as reported by teachers, there were significant main effects for gender and vagal regulation. However, these main effects were qualified by a marginally significant Gender x Vagal regulation interaction. Owing to this interaction, separate regressions were run for boys and girls. For boys, vagal regulation marginally contributed to the prediction of behavior problems as reported by teachers, after controlling for baseline vagal tone, total $R^2 = .04$, $R^2 \Delta = .03$, $F(1, 92) = 3.28$, $p <.08$, $\beta = .20$. On the other hand, for girls, vagal regulation did not significantly contribute to the prediction of behavior problems as reported by teachers, after controlling for baseline vagal tone, total R2 = .02, R^2A =.00, $F(1,117) = .104$, $p =.75$.

In terms of predicting social skills as reported by teachers, there were main effects for gender and vagal regulation, after controlling for baseline vagal tone, total $R^2 = .06$, $R^2 \Delta = .05$, $F(2,220) = 5.98$, $p <.01$. The standardized Rs for vagal regulation and gender were .15 ($p<.05$) and .17 ($p<.01$), respectively. Similarly, in terms of peer report of social skills (i.e., peer nominations of someone who –shares”), there were main effects for gender and vagal regulation, after controlling for baseline vagal tone, $R^2 = .11$, $R^2\Delta = .11$, $F(2,208) =12.25$, $p <.001$. The standardized Rs for vagal regulation and gender were .17 ($p<.05$) and .28 ($p<.001$), respectively. Thus, children who showed greater RSA suppression during the cognitive tasks, indicative of positive vagal regulation scores, were significantly more likely to obtain higher social skills scores as reported by teachers as well as being more likely to be nominated as someone who –shares” by peers. Overall, girls were more likely than boys to obtain higher social skills scores as reported by teachers and being nominated by their peers as someone who –shares.” There were no significant effects for Gender x Vagal regulation interactions.

Next, the relations between the mediators and the dependent variable, peer status, were examined. As depicted in Table 3, teacher report of social skills as well as peer nominations as someone who –shares” were positively correlated with peer status; teacher report of behavior problems and peer nominations of someone who –fights” were negatively correlated with peer status. Because the main effect between vagal regulation and behavior problems was only marginally significant for boys, it could only be tested as a possible mediator for boys. As a result of this gender difference, separate mediational models were tested for boys and girls. Additionally, to ensure that the mediation effects were not due to shared method effects, as the mediator –shares” and outcome peer status were both derived from peer nominations, separate mediational tests were run for teacher and peer reports.

The mediational test for girls via hierarchichal regressions is presented in Table 5 and examined whether teacher report of social skills as well as peer nominations of –shares” mediated the relation between vagal regulation and social preference. As indicated in the second step of the regressions, both measures of social skills, when tested separately, provided unique variance toward the prediction of

Table 5

Regression Analyses Testing Girls' Social Skills and "Shares" as Mediators of the Relation between Vagal Regulation and Social Preference

Predictor		β	R^2	R^2 change	F change
Social Skills as a Mediator (n = 111)					
Step 1.	Baseline vagal tone (L)	.09	.00	.00	0.45
Step 2.	Social skills (T)	.34***	.13	.13	15.69***
Step 3.	Vagal regulation (L)	.12	.14	.01	1.38
"Shares" as a Mediator (n = 117)					
Step 1.	Baseline vagal tone (L)	.07	.00	.00	0.43
Step 2.	"Shares" (P)	.65***	.43	.43	85.70***
Step 3.	Vagal regulation (L)	.04	.43	.00	0.26
Simultaneous testing of "shares" and social skills as mediators (n = 111)					
Step 1.	Baseline vagal tone (L)	.09	.00	.00	0.45
Step 2.	"Shares" (P)	.58***	.44	.44	42.15***
	Social skills (T)	.18*			
Step 3.	Vagal regulation (L)	.04	.44	.00	0.19

Note. P = peer report; T = teacher report; L = laboratory measure.
*$p < .05$. ***$p < .001$.

Table 6

Regression Analyses Testing Boys' "Shares," Social Skills, and Behavior Problems as Mediators of the Relation Between Vagal Regulation and Social Preference

Predictor		β	R^2	R^2 change	F change
Social skills as a mediator (n = 89)					
Step 1.	Baseline vagal tone (L)	– .10	.00	.00	0.12
Step 2.	Social skills (T)	.26*	.08	.08	7.23**
Step 3.	Vagal regulation (L)	.18	.10	.02	2.54
"Shares" as a mediator (n = 93)					
Step 1.	Baseline vagal tone (L)	– .04	.00	.00	0.04
Step 2.	Shares (P)	.57***	.33	.33	45.77***
Step 3.	Vagal regulation (L)	.09	.34	.01	0.89
Behavior problems as a mediator (n = 84)					
Step 1.	Baseline vagal tone (L)	– .06	.00	.00	0.19
Step 2.	Behavior problems (T)	– .33**	.12	.12	11.35**
Step 3.	Vagal regulation (L)	.13	.14	.02	1.27
Simultaneous testing of "shares," social skills, and behavior problems as mediators (n = 84)					
Step 1.	Baseline vagal tone (L)	– .06	.00	.00	0.19
Step 2.	"Shares" (P)	.57***	.45	.45	21.29***
	Social skills (T)	.02			
	Behavior problems (T)	– .23*			
Step 3.	Vagal regulation (L)	.05	.45	.45	0.35

Note. P = peer report; T = teacher report; L = laboratory measure.
*$p < .05$, **$p < .01$, ***$p < .001$.

social preference, after controlling for baseline vagal tone. The last step to test mediation is controlling for the mediators (–shares" and social skills) and assessing whether the independent variable (vagal regulation) still predicts the dependent variable (social preference). As hypothesized and depicted in Step 3, when vagal regulation was entered last in the regression, it no longer contributed unique variance toward the relation to social preference. The same findings emerged when simultaneously testing both –shares" and teacher report of social skills as mediators, indicating that not only do both mediators function independently from one another but also that the mediation effect is not due to a shared method effect.

The mediational test for boys via hierarchical regressions are presented in Table 6 and examined whether peer report of social skills, —shares,’’ as well as teacher report of social skills and behavior problems mediated the relation between vagal regulation and social preference. First these three potential mediators were assessed separately. As indicated in the second step of the regressions, both peer and teacher report of social skills and teacher report of behavior problems provided unique variance toward the prediction of social preference, after controlling for baseline vagal tone. The third and last step to test for mediation found that vagal regulation no longer contributed unique variance toward the relation to social preference when each of the three potential mediators was controlled for. The simultaneous testing of these three mediators revealed that only –shares” and teacher report of behavior problems emerged as significant mediators, with teacher report of social skills no longer contributing unique variance toward the prediction of social preference.

DISCUSSION

This study was designed to examine the relation between vagal regulation and children’s social competence, including peer status, social skills, and behavioral problems. Specifically, it examined whether kindergarteners with lower levels of vagal regulation would be more likely to exhibit deficits in social competence, as observed by teachers and peers, compared with kindergarteners with higher levels of vagal regulation. Mediational analyses were also used to address the potential mechanisms by which vagal regulation relates to children’s peer status.

First, the relation between vagal regulation and children’s peer status was examined. Children with higher levels of RSA suppression during the cognitive tasks, indicative of positive vagal regulation, were more likely to obtain a higher peer status. This finding was consistent with our hypotheses and with the work of other investigators such as Stifter and Corey (2001), who found that infants with greater levels of vagal regulation during a cognitively challenging task were rated by the experimenters as more socially approaching. Furthermore, these findings support Porges et al.’s (1996) vagal –brake” (i.e., vagal regulation) as a neurophysiological mechanism for appropriate social behavior. This is also the first study to examine vagal regulation as it relates to a peer assessment of social competence: peer status. Given the numerous negative outcomes associated with peer rejection, our finding is the first to examine a potential physiological marker for peer rejection as children with lower levels of vagal regulation were indeed more likely to be rejected by peers. This finding also supports Porges and colleagues’ differentiation of the two dimensions of vagal tone (baseline vagal tone and vagal regulation) as only vagal regulation was associated with children’s peer status. This is further evidence that vagal regulation is likely a better and more specific physiological marker for appropriate social behavior than is baseline vagal tone.

Owing to the significant finding between vagal regulation and children’s peer status, mediational analyses were conducted to examine possible mechanisms by which vagal regulation relates to children’s social competence. Based on previous research, it was expected that the role of vagal regulation in children’s social competence lies in its ability to facilitate the development of children’s social skills repertoire and decrease their behavior problems leading to better peer status. Thus, in exploring the link between vagal regulation and peer status, it was of particular importance to determine whether it was through better social skills, fewer behavior problems, or both that vagal regulation related to peer status. Using Baron and Kenny’s (1986) mediational approach, we tested a model in which a child’s social skills and behavior problems, evidenced in the kindergarten classroom, would serve as mediators between vagal regulation and peer status.

First, and partially consistent with our hypotheses as well as with previous research (Calkins & Dedmon, 2000; Porges et al., 1996), vagal regulation was negatively related to teacher reported behavior problems only for boys, although this relation was only marginally significant. Boys who showed greater RSA suppression during the cognitive tasks were less likely to exhibit behavior problems as reported by teachers. The fact that no such finding emerged with peer report of behavior problems may suggest a difference in the contextual variability of negative social behavior observed by teachers and peers. Eisenberg et al. (1996) suggested that perhaps due to gender stereotypes and different expectations teachers are more sensitive to noticing disruptive negative behaviors in the class and are thus more likely to observe such behavior in boys. However, we found that peers were also more likely to nominate boys as someone who “fights”; yet no relation to vagal regulation was found. Perhaps peers have a higher threshold for disruptive behavior as even well-regulated boys (with high levels of vagal regulation) may engage in some rough play behavior with their peers. This lower range of behavior problems among peers may make it difficult to find a significant relation between vagal regulation and peer nominations of “fights.” On the other hand, in a classroom setting, well-regulated boys may be more likely to comply with class rules and obey the teacher, whereas dysregulated boys may not be able to adapt to the setting and may continue to be disruptive.

Vagal regulation was not related to behavior problems among girls, a finding that contradicts our hypothesis and some prior research in this area. It may be that, by the time girls enter kindergarten, socialization processes aimed at the expression of anger (Fabes & Eisenberg, 1992) override physiological mechanisms in such a way that girls are better at masking their anger (Underwood, Coie, & Herbsman, 1992) or managing behavior to comply with the demands of the classroom. At the same time, it is important to recognize that only a small number of studies have examined the relations between vagal regulation and behavior problems in community samples of boys and girls, and such findings are clearly in need of replication. Examining younger children who are already exhibiting appropriate behavioral and emotion regulation despite their physiological functioning is an important step in understanding how this dissociation between physiology and behavior develops. Exploring how socialization practices (e.g., parenting methods) as well as learning (e.g., modeling parental behavior) affect children’s emotion regulation development, both behaviorally and physiologically, will undoubtedly contribute to our understanding in this domain.

As hypothesized, vagal regulation was related to better overall social skills as reported by teachers as well as greater peer nominations for someone who “shares.” These findings extend support for the role of vagal regulation or the vagal “brake” in social behavior in two ways. First, this study provides evidence for Porges et al.’s (1996) vagal “brake” theory as it directly relates to children’s positive social behavior—in the form of better individual social skills—not fewer behavior problems as past research had found (Calkins & Dedmon, 2000; Porges et al., 1996). Second, it supports the notion that the modulation of arousal via the vagal “brake” facilitates an organism's ability to engage and disengage with the environment. This ability can be thought of as a core aspect of good social skills as children must know when to engage appropriately with other kids (i.e., talk to or play with them) and when to disengage with them (i.e., ignore them). This constant shift in communication and behavioral engagement and disengagement during social interactions may be easier for children who are able to maintain physiological homeostasis during arousing situations.

The current study found that the mediational processes that account for the relation between vagal regulation and peer status differed for boys and girls. For girls, only social skills as reported by teachers and peers (―shares") mediated the relation between vagal regulation and peer status, whereas for boys, both social skills (peer report) and behavior problems (teacher report) mediated this relation. This marks the first study that has examined the mechanisms by which vagal regulation relates to peer status and extends Porges et al.'s (1996) ―vagal brake" theory by demonstrating gender differences in how vagal regulation relates to greater social competence. It appears that for boys, higher levels of vagal regulation relate to greater peer status through better social skills and fewer behavior problems whereas for girls vagal regulation relates to peer status through only better social skills. Examining gender differences in physiological processes has been suggested by Beauchaine (2001), who argued that some earlier findings linking baseline RSA to social competence for boys only (Eisenberg et al., 1995, 1996; Fabes et al., 1993) were limited by restricted ranges on all indices for girls as well as reduced variability in baseline RSA. Because our study's RSA variability for boys and girls did not differ, it allowed us to examine more accurately potential gender differences in how a physiological mechanism relates to social behaviors. Additionally, our examination of RSA suppression (i.e., vagal regulation), while controlling for baseline RSA, gave us a more precise proposal at how a regulatory physiological mechanism relates to social behavior.

Perhaps in infancy and toddlerhood the role of vagal regulation is simply to inhibit impulsive reactions to stressors, which can be thought of as be havior problems. As children get older and develop more sophisticated cognitive skills, however, the link between physiological regulation and their behavior may become managed by more advanced cognitive processes such as social skills. For example, it may be cognitively less demanding to punch a peer reactively as a result of a stolen a toy compared with using problem-solving skills. This cognitive shift in the management of behavior may explain our robust finding (for both girls and boys) that vagal regulation is related to social competence—as measured by peer status—through social skills. The use of cognitive processes for better social skills may be facilitated by successful modulation of arousal via vagal regulation. This modulation of arousal during stressful circumstances facilitates the maintenance of physiological homeostasis, which may free up metabolic resources to be used by higher cognitive processes. Boys, however, may continue to use vagal regulation for the inhibition of behavior problems due to their potentially slower physiological maturation compared with girls or simply due to societal norms that find some forms of disruptive behavior for boys more acceptable (e.g., rough play), therefore necessitating regulation.

In summary, this study's results provide support for the role of vagal regulation in children's social competence. It appears that greater vagal regulation is related to better peer status by facilitating the use of social skills for boys and girls as well as inhibiting behavior problems for boys only. This study has several important strengths that should be noted. First, the design used multiple reporters (peers and teachers) including physiological data derived from several challenging episodes ensuring the measure of appropriate arousal levels. Second, peers were included as a source of information, not only in terms of assessing peer status within the classroom but also as reporters of behavior problems and social skills. Lastly, this study drew from a community- based sample that included children with varying degrees of behavior problems. Despite the strengths of this study, it is clear that the concurrent nature of the study precludes definite conclusions on the causal role of vagal regulation in the development of social competence. A longitudinal design examining whether infants' vagal regulation predicts their social competence in the future would be needed to further solidify the role of vagal regulation in developing appropriate social behavior.

Peer nominations of social skills and behavior problems were also limited to one question per construct (―shares" and ―fights"), which may have prevented a more detailed assessment of which specific components of social skills and behavior problems are related to vagal regulation. Another important issue to consider was the moderately high correlation between peer nominations of ―shares" and peer-reported social preference. Our results illustrated that the mediation effect found via ―shares" was not solely due to shared method effects, as teacher report of social skills was also a significant mediator in the relation between vagal regulation and social preference. However, the question of whether young children have difficulty distinguishing positive behaviors from overall like- ability or whether sharing behavior is a distinguishable but important feature of being liked in kindergartener, as past research has found (Coie et al., 1982, Keane & Calkins, 2004), still remains. Future studies using observational methods in the classroom may be able to determine young children's accuracy when reporting peers' social behavior. It may also be beneficial for future studies using peer reports to determine which specific components of social skills (e.g., eye contact, verbal skills, cooperation, and assertiveness) are related to overall peer status as well as higher levels of vagal regulation. This type of examination would also provide evidence for the Social Engagement System, outlined by Porges (2003), which specifies the importance of the vagus nerve in enabling complex facial gestures, vocalizations, social gesturing, and orientation, which are thought of as important behaviors for engaging in social communication. We also did not examine the relation between vagal regulation and internalizing problems due to our young sample. However, given recent findings that depressed adults with higher levels of vagal regulation are more likely to recover from depression (Rottenberg, Salomon, & Gross, 2005), it may be important to examine the role of vagal regulation in the onset of such internalizing problems, perhaps as early as preadolescents.

In addition, it is clear that although many of the relations tested were significant, they were modest in magnitude and accounted for a small portion of the variance. Thus, other variables such as socialization practices and parenting techniques should be considered to determine how those environmental factors interact with children's physiological make-up. One recent study by Kennedy, Rubin, Hastings, and Maisel (2004) found that toddler's baseline vagal tone at age 2 predicted parenting style at age 4. Kennedy et al. (2004) argued that physiologically dysregulated children may elicit negative parental behavior. It is important to examine this relation with vagal regulation to determine whether this dysreg ulation is indicative of a child's overall inability to maintain homeostasis, as indexed by baseline vagal tone, or more specifically linked to an inability to modulate arousal when facing a more stressful situation, as indexed by vagal regulation. Lastly, the bidirectional influence of environmental factors on children's physiological regulation remains unexplored. Perhaps, positive parenting behavior on children who have difficulty with physiological regulation early on can change their physiological regulation in the future. Examining such environmental and physiological interactions may be important for the development of early prevention programs.

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