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Preterm stress behaviors, autonomic indices and maternal perceptions of infant colic

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Abstract

Background—While biological and behavioral stress response systems are intact in early gestation, preterm infants' behaviors are often more subtle and difficult to interpret compared to full-term infants. They are also more vulnerable for regulatory issues (i.e., colic) that are known to impact caregiver-infant interactions. Biobehavioral measures such as behavioral responsivity and heart rate variability (HRV), particularly cardiac vagal tone, may help to elucidate preterm infants' stress/regulatory systems.

Purpose—Test the hypotheses that preterm infants' consoling behaviors and high-frequency (HF) HRV in the first week of life are significantly associated, and they are inverse correlates of future colic risk.

Methods/Search Strategy—Thirty preterm (mean, SE: 32.7±0.3 weeks PMA) infants underwent direct NIDCAP® observation during routine care, and had HRV measurements during their first week post-birth. Sixty-three percent of mothers completed the Infant Colic Scale at 6–8 weeks adjusted postnatal age. Non-parametric tests were used to determine associations among behaviors, HRV, and maternal perceptions of infant colic.

Findings/Results—Self-consoling behaviors were positively associated with HF-HRV (vagal tone). In addition, stress behaviors were positively associated with low frequency/high frequency HRV (sympathetic dominance). Infants who displayed more stress behaviors also demonstrated more self-consoling behaviors. No significant associations were found with colic.

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Conflicts of interest: None.

Disclosure Statement
None.

Implications for Practice—HF-HRV provides information on the infant's capacity to modulate stress, and is a useful, non-invasive measure when behaviors are more difficult to discern.

Implications for Research—Further study in a larger sample is needed to determine if behavioral stress measures and HF-HRV may be useful to determine colic risk.

Keywords

Preterm infants; HRV; stress behaviors; colic

Background and Significance

While the survival of preterm infants has increased, the stress associated with premature birth and the necessary therapies required to sustain life during hospitalization are particularly high in the early weeks post birth. Preterm infants are known to have intact biological and behavioral stress response systems as early as 25 weeks gestational age.^{1,2} Common stress-inducing procedures include standard caregiving practices (e.g. repositioning, diaper changes, and bathing) and common medical interventions (e.g. physical exams, endotracheal suctioning, gastric tube insertion, and heel prick blood sampling).^{2,3} It has been demonstrated that preterm infants may be exposed to as many as 134 of these stress-inducing procedures in the first two weeks of life.⁴

Stress-inducing procedures activate the locus coeruleus (LC/NE) sympathetic system and the hypothalamic-pituitary-adrenal (HPA) axis, which consists of corticotropin-releasing hormone (CRH) neurons of the hypothalamus, the pituitary, and the adrenal glands.⁵ The stress system acts to protect the body by responding to internal and external stressors in order to achieve stability for the organism.⁶ Stimulation of LC/NE also leads to behavioral arousal, fear, and enhanced vigilance, manifested as stress behaviors.⁷ For the neonate these are observable as finger splay, yawn, sneeze, gaze aversion, and defensive motor actions in upper and lower extremities, i.e., kicking of legs.¹ HPA-immune activation and release of pro-inflammatory cytokines cause the induction of behaviors, known as *sickness behaviors*, specifically, fatigue or lethargy that promote rest to assist in recovery of injury or illness.^{7,8}

Because the pathways for this immune-brain interaction are in place, it is plausible that many of the same sickness behaviors seen in older children and adults would be observable in high-risk newborns. However, psychobiological manifestations of illness in the preterm infant may be less apparent than with the full-term infant as the preterm infant's behavioral repertoire is not fully mature.¹ In addition, because the infant's temperamental attributes contribute significantly to patterns of sucking, feeding irritability/mood, it may be much more difficult to discern sickness behaviors from behavioral style in the temperamentally challenging infant.⁹ Lethargy, diminished tone, and diminished motor activity may be observed as the first indicators of sickness or *stress overload* in the preterm infant. These behaviors are adaptive as the inactivity and loss of alertness serve to minimize attentive interactions with caregivers in order to conserve the energy required for restorative processes.¹⁰ Further, the subtle behavioral cues of distress (i.e., finger splay, yawn etc.) are important as early stress indicators and serve a protective function to alert the care provider that the infant has a limited capacity to handle further stress.¹¹ The understanding of these

complex behavioral and stress regulatory systems may be elucidated by adding biological measures such as heart rate variability (HRV).

HRV represents instantaneous variations in heart rate as well as interval changes in beat-to-beat variability.¹² In addition to important applications in maternal-fetal status, studies have shown HRV to be an important prognosticator of impending neonatal illness.^{13–15} Increased HRV reflects adequate functioning of neural control mechanisms and high stress adaptability.^{16,17} In contrast, attenuated HRV has been associated with pathological disease states including feeding bradycardia, hypoxemia, periventricular-intraventricular hemorrhage, perinatal asphyxia, acute sepsis and necrotizing enterocolitis.^{13,14,18–20} In a previous study at our own institution, HRV measures were utilized to identify the risk of GI dysfunction in preterm infants. We found low cardiac vagal tone at day 5–7 of life (i.e., a low value of high frequency HRV) predicts GI dysfunction as many as 3 weeks prior to the development of clinical symptoms.²⁰ In fact, in the preliminary analysis of an existing multi-site study currently in progress, we found low vagal tone at day 5–7 of life, in apparently *healthy* neonates, was associated with the development of both feeding intolerance and necrotizing enterocolitis (NEC).²¹ In these studies we found behavioral state to be an important confounder to consider when measuring HRV, because HRV is affected by motor activity, a parameter that distinguishes between active and quiet sleep.²² In addition, factors such as respiration, stress, posture, feeding, temperature, time of day, and endocrine hormones are known to impact measurement.^{23,24}

Spectral power analysis is a frequency domain measure that assesses the underlying system control of the cardiac rhythm. It is a non-invasive modality using analog R to R wave data via the electrocardiogram to quantify autonomic activity and to assess cardiovascular response.^{12,25} Using fast Fourier Transform (FFT), the graphic representation of the power spectral function is plotted against the bandwidth frequency.^{12,26} The bandwidth frequencies of spectral analysis divide into ranges: low frequency (LF) bandwidth reflects both sympathetic and parasympathetic influences, and high frequency (HF) bandwidth, reflects parasympathetic nervous system (PNS) activity.^{26,27} Each of these bandwidths represents an underlying physiological mechanism that affects HRV. The PNS known to regulate internal state, facilitate digestion, and conserve energy by slowing heart rate, also serves as an index of homeostasis.^{26,28,29} While PNS function can be measured by HRV as early as 24 weeks gestation, maturation continues throughout gestation and during early infancy.³⁰ The HF bandwidth, representative of cardiac vagal tone, has been identified as a method to index both the stress response and the individual's vulnerability to stress, as described by Porges' polyvagal theory.³¹ This theory purports that behaviors are closely associated with the three ANS components: two vagal subsystems that control communication and immobilization, and the SNS, which controls mobilization.³¹ Under most situations, the greater the range of phasic increases and decreases in neural efferent output via the vagus nerve to the heart, the healthier the individual.^{17,32,33} In sum, vagal suppression of sympathetic system activation is important for sympathovagal balance and recovery from stress. Cardiac vagal tone measured by HF-HRV provides information on the integrity of cardiac neuroregulatory activity, especially modulation of heart rate.³³

Previous studies have demonstrated the association between cardiac vagal tone and attention/regulation issues in infancy and early childhood. In term-born infants at 3–6 months of age, higher parent conflict was associated with higher environmental sensory sensitivity among infants with low cardiac vagal tone, but not among infants with high cardiac vagal tone.³⁴ Among preterm infants, low cardiac vagal tone was directly associated with emotion and attention regulation, and behavior problems at one, two and five years.³⁵ These regulatory issues can create significant difficulties in caregiver-infant interactions and parenting competency.

One such challenge during infancy is colic, i.e., high-pitched, inconsolable cries during the first 3 months of life, lasting for 3 or more hours per day for 3 or more days per week, in otherwise healthy infants.³⁶ Approximately 20% of infants exhibit colic symptoms,³⁷ and the incidence of colic increases with decreasing gestational age, with higher risk of colic among preterm and small for gestational age infants compared with term-born infants.³⁸ While the exact cause of colic is unknown, several mechanisms have been proposed such as immaturity of gastrointestinal (GI) motility and absorption, and parent-infant interaction problems.^{37,39,40} Colic onset begins in the first 3 weeks of life, peaks around 6–8 weeks adjusted for gestational age, and usually ends by 3 months of age.⁴¹ While colic is short-lived, the impact on families is striking such as parental feelings of being overwhelmed, guilt, anger, frustration, and less optimal parent-infant interaction.^{42,43} Moreover, there is no known biomarker for the early detection of colic risk in preterm infants rendering the parents of an apparently non-colicky infant unprepared for proper care should colic symptoms arise later.

Considering that cardiac vagal tone, measured by HF-HRV is a useful measure of parasympathetic activity important for gastrointestinal function and motility, and to modulate stress and stress associated behaviors, we aimed to test two hypotheses: i) preterm infants' behaviors and HRV are significantly associated, and ii) preterm infants' behaviors and HF-HRV in the first week of life are useful correlates of future colic risk.

Methods

This study was the first cohort of a larger multiple cohort comparison study to evaluate the utility of cardiac vagal tone to predict GI dysfunction in preterm infants.²⁰ In the present study our interest is in the protective effects of early stress-regulation and cardiac vagal tone on later regulation and GI function.

Subjects

The Penn State Hershey Institutional Review Board and ethics review committee approved the study. Parental consent was obtained prior to enrollment of 30 preterm infants (from both singleton [70%] and multiple gestation [30%] pregnancies) receiving care in a level IV-C NICU of the Penn State Health Children's Hospital. None of the infants' mothers had a history of drug/substance abuse, chronic physical illness (i.e., autoimmune or endocrine disorder) or psychiatric illness requiring pharmacotherapy as these issues are known to impact infant autonomic and behavioral regulation. In addition, the infants were without congenital or neurological abnormality at birth verified by cranial ultrasound at 7–10 days of

life, without cardiac abnormalities, and off mechanical ventilation by day 5 of life. The mothers of enrolled infants completed and returned the Infant Colic Scale by mail at 6–8 weeks adjusted postnatal age.

Materials

Naturalistic behavioral observation—The NIDCAP® (Newborn Individualized Development and Assessment Program) observation method records infants' activity, sleep-wake state, and behavioral responses to standard caregiving procedures using a 2-minute-by-2-minute systematic format.¹ Eight of the 85 NIDCAP® behaviors/movements indicating avoidance or stress are associated with pain/distress.⁴⁴ The present study focused on two behavioral response systems: total stress behaviors (facial, visceral, motor, attentional), and self-consoling behaviors (mouth/suck, hand to mouth, grasp, hold, hand/foot clasp); these behaviors give insight into the extent of stress infants are experiencing and their ability to self-regulate. Total stress behaviors and self-consoling behaviors were calculated by the total frequency of corresponding behaviors for each domain.⁴⁵

Heart rate variability—HRV was obtained as described previously.²⁰ Briefly, surface electrocardiogram (ECG) R-wave data were acquired at a sampling frequency of 1 kHz using standard lead II bipolar chest lead placement (Biobench, National Instruments, Austin, TX, USA). A customized software package (HRV Analysis Software, Mindware Technologies, LTD, Westerville, OH, USA) was used for HRV spectral analysis. Each pre-selected 120sec-long segment (average 7 segments for each infant) of the R-R wave was cleared manually of ectopic foci and motion artifacts prior to generation of the spectral frequency output via fast Fourier Transform (FFT). HRV data collection was repeated as needed the same or next day to assure validity of data. FFT of epochs were averaged using LF (bandwidth 0.03–0.29Hz) and HF (0.3–1.3Hz). The HF bandwidth range was calculated from the mean $\pm$ 2SD of the spontaneous resting breath rates (20–80 breaths/min) of the infants in our sample population. The sum of LF+HF was calculated to determine the total power (TP) spectra, to demonstrate the relative contributions of LF and HF to TP, respectively. The LF/HF ratio was calculated to estimate sympathovagal balance, with higher ratios suggesting sympathetic dominance.²²

Score for Neonatal Acute Physiology (SNAP)—SNAP is a well-validated measure used to determine infants' illness severity based on 26 physiologic measurements from clinical tests and vital signs in the first 24 hours of admission.^{46–48} Each item is scored between 0 to 5 points with the total score representing the severity of illness.⁴⁶ In several studies, SNAP was shown to be a significant independent predictor of neonatal mortality among preterm infants, adding prognostic value to other perinatal risk factors,⁴⁹ in predicting mortality compared to when birth weight and Apgar scores were considered alone^{50,51}.

Infant Colic Scale—The Infant Colic Scale (ICS) comprises 22, 6-point Likert-scale items (1 = strongly agree to 6 = strongly disagree) measuring 5 theoretical domains based on parental perception of infants' colic symptoms (see Appendix A).⁵² Appropriate items (e.g., “Baby may still be vomiting when time for the next feeding”) are reverse-scored such that a

higher summary score represents higher colic symptoms (See Appendix). A total colic score (i.e., total colic symptoms an infant exhibits) was created by summation of the 5 domains, with a minimum total score of 22 and a maximum total score of 132. In addition to the original study by Ellett et al.⁵², the ICS has been tested and found to be a valid and reliable measure among Turkish populations.⁵³ Based on the authors' report, the Cronbach alpha coefficient of factor analysis for each of the five domains ranged from .45 to .91, with a median of .65, and the α coefficient for the total ICS was .73.⁵² In our study, the Cronbach alpha coefficient for each of the five domains ranged from .33 to .99, with a median of .59, and the α coefficient for the total ICS was .69.

Type of feeding at discharge—Information on the type of feeding at an infant's discharge was collected from the medical record. Three types of feeding were identified and coded as: 0 = exclusively formula fed, 1 = formula and breast milk fed, and 2 = exclusively breast milk fed. This coding scheme, whereby feedings containing breast milk were ranked higher compared with non-breast milk feedings was based on the demonstrated beneficial effects of breast milk on health outcomes and infant development.^{54,55}

Procedure

SNAP was completed using physiologic data from the medical record from birth to 48 hours of admission to the NICU by trained coders with established inter-rater agreement .85. On day 4–5 of life, infants were observed real-time by a NIDCAP® certified rater during routine morning nursing care. The behavioral observation lasted approximately 30–45 minutes and included 15 minutes of pre-care, 5–10 minutes of care, and 15 minutes of post-care. Additionally, simultaneous measurements of heart and respiratory rates and oxygen saturations were measured while video-capturing the infants' responses to the stress of handling. Two naïve coders completed behavioral training for identifying preterm infant stress and consoling behaviors using an established method of training and reliability testing as previously described.⁵⁶ Inter-rater agreement of behavioral coders was consistently .85. Coders' ratings of behavioral response data for infant stress behaviors and self-consoling behaviors were based on the NIDCAP® coding scheme.^{45,57} HRV measures were done in the afternoon on day 5–7 of life for 30–40 minutes after scheduled care and feeding, when the infants were in a light sleep state to control for circadian, feeding and behavioral state influences on HRV. This time period was selected as a critical window to evaluate autonomic system regulation as a time when transition ex-utero and recovery from the stress of birth had occurred. HRV measures were done the day after the NIDCAP® observation in order to avoid the EKG motion artifact associated with caregiving, which causes difficulty with HRV sampling and analysis.²² The ICS was completed by mothers when their infants were 6–8 weeks adjusted postnatal age. Survey packets were mailed with instructions on completion of ICS and delivered to the addressee with a prepaid return postage envelope. A reminder follow-up phone call at 2 weeks post mailing and payment with a \$25 gift card once surveys were returned were used to enhance participation.

Statistical analysis

SPSS version 24 (IBM Corporation, Armonk, NY, USA) was used for data entry and analyses. Descriptive statistics (frequencies, means, medians and scatterplots) were done and

all variables were checked for outliers and normality before analyses. Differences in demographics or outcomes between the full and subsample infants were determined using independent samples *t* tests for continuous variables and Mann Whitney U tests for non-parametric data. Chi-square tests were used for categorical data. Non-parametric, Spearman correlation coefficients were used to examine the associations among behavioral responses to routine care, HRV and maternal perception of colic. All tests were two tailed at a 5% significance level. Because HRV parameters were non-parametric, HF-HRV and LF-HRV were natural log transformed to correct for skewness and kurtosis on tests of normality.

Results

Study infants were relatively stable with low morbidity estimates by SNAP at birth. Mothers were predominately white, non-Hispanic and were the primary caregivers for their infants (Table 1). Nineteen of 30 mothers (63%) completed the Infant Colic Scale (ICS), with total ICS scores $M \pm SE$ 65.58 ± 3.60 , and range from 34–88. Raw data for the key variables of interest are presented in Table 2. Additionally, 7/19 (i.e. 37%) of the infants with colic information were exclusively formula fed, 2/19 (11%) infants were on combined breast milk and formula, and 10/19 (53%) were exclusively breast fed at the time of NICU discharge.

We found that preterm infants' total stress behaviors (frequency of stress behaviors during the handling interaction) and self-consoling behaviors (frequency of behaviors to console oneself during the handling interaction) were directly associated with HRV. Specifically, HF-HRV, i.e., cardiac vagal tone, was positively associated with the frequency of demonstrated behaviors to self-console, such that with higher vagal tone there were more self-consoling behaviors, $r_s(df=28) = .49, p = .007$ (Figure 1, Table 3). In addition, elevated total stress behaviors were positively associated with higher LF/HF ratio [$r_s(28) = .44, p = .014$, Table 3]. Infants that displayed more total stress behaviors also demonstrated more self-consoling behaviors, $r_s(28) = .52, p = .003$. Neither stress behaviors nor any of the HRV indices were significantly associated with the total ICS. Further, the types of feeding at the time of NICU discharge (i.e., formula, breast milk) were not significantly associated with the total ICS.

Discussion

Our findings support the hypotheses that behavioral responses to the stress of handling, and resting HRV in the first week of life are positively associated; however, no relationships were found between stress behaviors and colic or HRV indices and colic. Specifically, i) higher stress behaviors were associated with *higher* sympathetic dominance, i.e., LF/HF; and ii) higher self-consoling was associated with *higher* vagal tone, i.e., HF. The demonstrated relationships among these behaviors and HRV may be explained by the polyvagal theory, as previously described, whereby the ANS interacts with response systems such as HPA axis and immune systems to regulate social behaviors.^{31,58} Similar to the present results, studies in term infants also have shown the association between HRV and infant regulatory behaviors. Among 5-month old infants born at term, the infants' ability to increase vagal tone during an attention task (replacement of an adult's smiling with a blank face) was associated with sustained engagement; demonstrating vagal tone is necessary to support the infant's emotional state.⁵⁹ Further, VLBW infants vagal maturation during the neonatal

period was an independent predictor of later social competence.⁶⁰ Our findings also suggest that vagal tone early in the postnatal period reflects the infants' ability to self-regulate and modulate stress.

An interesting finding in our study is the positive association between LF/HF ratio and total stress behaviors. Considering that LF/HF ratio represents sympathovagal balance with higher values indicating sympathetic dominance,⁶¹ this suggests preterm infants' higher biological sensitivity to the stress of handling, specifically, sympathetic arousal is associated with high total stress behaviors.⁶¹ As expected, we found stress behaviors and self-consoling behaviors were positively associated. This pattern of association whereby preterm infants demonstrate both higher behavioral responsivity (e.g., reactivity/sensitivity) as well as higher need to self-console in response to stress suggests higher regulatory capability.⁶¹ In fact, our findings demonstrate that those infants observed to have higher stress responsivity to handling also showed more competence in self-consoling. Similarly, Ohgi et al.⁶² observed that preterm infants at term adjusted age with a high level of crying showed higher behavioral responsivity compared to infants with a low level of crying. Self-consoling and crying behaviors are adaptive and necessary for infants' social/emotional needs to be met.

Our hypotheses predicting relationships between colic and behaviors and between colic and HRV were not supported. While several studies have been published on HRV and colic in term infants,^{63,64} to our knowledge our study is one of the first to measure HRV and colic in preterm infants. Between colic and non-colic term infants at 8 weeks of age, no difference in HRV was found during non-rapid eye movement sleep and rapid eye movement sleep stages, and in response to spontaneous sleep-related movements.⁶³ Similarly, another study in term infants reported no difference in baseline vagal tone between colic and non-colic infants.⁶⁴ In these studies, colic was defined as crying for 3 or more hours on 3 or more days/week by maternal report and daily diary, respectively. Similarly, we did not find a relationship between colic measured by ICS and HRV indices.

Limitations

Our study has several limitations. This study was a feasibility study to determine the procedural approach of behavioral and biological stress measures during an infant's first week of life; therefore, our sample size was limited to 30 infants. Although our response rate for the post-discharge surveys was only 63% despite a follow-up phone contact and monetary incentive, low response rates post discharge are known to be a challenge in this population. Due to the small sample size for the colic subgroup, our negative findings should be taken with caution. In addition, the Infant Colic Scale is a major limitation because the internal consistency reliability reported by the authors of the scale is lower than that of what is generally acceptable, and was also lower than acceptable in our preterm sample. However, to our knowledge, it is the only published scale of colic. Therefore, the fact that we did not find a significant relationship does not mean that a true relationship did not exist.

It also is important to note that for all of these studies including our own, colic was determined through maternal perception of their infant's colic behaviors. Mothers' perceptions of infant cry and acoustic characteristics of colic and non-colic cries have been

found to reliably identify colic.⁶⁵ Nonetheless, it is possible that mothers may over or underreport colic symptoms through questionnaires, rather than in a clinic setting where the health care provider can observe and interact with the infant and mother, and *assess colic directly*.

Implications for Practice

The importance of this study resides in the significant associations where early preterm stress responses and HRV measures represent infants' vulnerability to stress and their adaptive regulatory abilities. When clear behavioral cues are more difficult to discern, HRV is useful as a non-invasive and objective method of identifying stress and stress recovery patterns, and may provide valuable information to aid in the clinical assessment of an infant's vulnerability to stress.

Regarding the preterm infant's risk for colic, it is important to emphasize and reassure mothers that if colic symptoms appear, colic symptoms are temporary, and can be successfully ameliorated with strategies to promote regulation such as use of front carriers, gentle up-down rocking motions, and minimizing environmental changes to avoid overstimulation. An intervention is likely to be more successful when the advice in caring for an infant with colic is individualized, which is usually finding the easiest way of caregiving for each individual infant-caregiver dyad, and supporting them in doing so. Of course, it is also important to include fathers in education and support of the preterm infant at risk for the development of colic. Having and caring for a preterm infant is often an overwhelming experience for families, and this could be exacerbated if the infant develops colic symptoms.

Future Research

Future studies in a larger, more heterogeneous sample should be conducted to examine relationships among behaviors, HRV and colic. Continued efforts should focus on a comprehensive assessment of colic using a valid/reliable measure, and to include multiple observers (i.e., mother, father, and clinician) at multiple observation locations (i.e., home, office setting). Considering the complexity and multiple causes of colic, next steps in this program of research should include the contributions of maternal/ paternal characteristics, parenting style and infant temperament on infant colic outcomes. Moreover, testing maternally driven nurturing interventions to enhance maternal/infant synchrony, i.e. parasympathetic co-regulation and their impact on gastrointestinal function in infancy are necessary.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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What this Study adds

- Preterm infant behaviors are significantly associated with HRV.
- HRV is a useful, non-invasive measure to understand preterm infants' stress regulation and autonomic systems especially when their behaviors are subtle.
- Findings explore the associations among preterm infant behaviors, HRV and colic.

Summary of Recommendations for Practice and Research

What we know

- Preterm infants show unique temperament characteristics, and their behaviors are often subtle and difficult to interpret.
- HRV describes the variations of instantaneous heart rate and R-R intervals, and infers an infant's regulatory system and health such that increased HF-HRV reflects adequate functioning of neural control mechanisms and high stress adaptability.
- Approximately 20% of infants exhibit colic symptoms. The incidence of colic increases with decreasing gestational age, with higher risk of colic among preterm and small for gestational age infants compared with term-born infants.

What needs to be studied

- Understanding the associations among preterm infants' stress and self-consoling behaviors and HRV may provide valuable information to aid in the clinical assessment of an infant's vulnerability to stress.
- Investigating the relationships among preterm infants' behaviors and HRV, and future colic risk in a larger, more heterogeneous sample is needed.
- Utilizing a valid/reliable comprehensive assessment of colic that includes multiple observers (i.e., mothers, fathers, and clinicians) at multiple locations (i.e., home, clinic) should improve colic measurement.
- Considering the complexity and multiple causes of colic, future approaches should examine the contributions of maternal/paternal characteristics, parenting style, and infant temperament on infant colic outcomes.

What we can do today

- Increase the awareness and understanding of preterm infants' stress and self-consoling behaviors.
- Utilize HRV in the early weeks postnatally to understand infants' abilities to self-regulate and modulate stress.
- Individualize the care of preterm infants based on their unique biobehavioral patterns of stress and stress recovery.

Figure 1.

Scatter plot, indicating the direct relationship between natural log of HF and self-consoling behaviors, $r_s(28) = .49$, $p < .01$.

Table 1
Between Group Differences for Total and Subsample Infant and Maternal Characteristics

	Total Sample (N=30)			Subsample with ICS (N=19)			Difference ^d (p value)		
	Mean	SE	Min	Max	Mean	SE		Min	Max
Male gender (%)	50	--	--	--	63.2	--	--	--	0.06
SNAP	4.13	0.44	0	9	3.95	0.52	0	8	0.58
PMA at birth (weeks)	32.69	0.27	29	35	32.82	0.30	30	35	0.52
Birth weight (grams)	1877	74	1256	2803	1904	101	1256	2803	0.64
Days on oxygen support	5.03	1.57	0	41	5.32	2.16	0	41	0.82
PMA at discharge (weeks)	36.39	0.23	35	40	36.36	0.31	35	40	0.89
Length of stay in NICU (days)	25.83	2.64	3	54	24.68	3.20	3	54	0.56
White, non-Hispanic race/ethnicity (%)	80	--	--	--	94.7	--	--	--	0.03
Maternal age (years)	26.97	1.00	17	41	26.89	1.01	18	32	0.93
Maternal marital status, married (%)	66.7	--	--	--	68.4	--	--	--	0.80

Note:

^aStatistical differences were calculated using independent samples *t* tests, and chi-square tests for gender, race, and marital status.

ICS = Infant Colic Scale, SNAP = Score for Neonatal Acute Physiology.

Table 2
Between Group Differences for Total and Subsample NIDCAP® Behaviors, HRV Indices and Colic

	Total Sample (N=30)				Subsample with ICS (N=19)				Difference ^a (p value)
	Mean	SE	Min	Max	Mean	SE	Min	Max	
LF (ms ²)	182.62	48.05	8.06	1419.01	211.26	73.49	8.45	1419.01	0.44
HF (ms ²)	34.40	7.44	1.14	191.88	39.03	11.04	1.47	191.88	0.42
Total Power (ms ²)	217.01	54.59	9.20	1610.88	250.29	83.26	10.73	1610.88	0.43
LF/HF Ratio	6.12	.71	1.74	22.13	6.43	1.08	1.74	22.13	0.58
Total Stress Behaviors	50.63	3.93	8	103	52.95	3.29	33	84	0.89
Self-Consoling Behaviors	12.30	1.81	0	30	12.11	2.40	0	30	0.45
ICS Total Score	--	--	--	--	65.58	3.60	34	88	--

Notes:

^aStatistical differences were calculated using independent samples *t* tests for continuous variables and Mann-Whitney U tests for non-parametric data.

NIDCAP® = Neonatal Individualized Developmental Care and Assessment Program, LF = low frequency HRV, HF = high frequency HRV, ICS = Infant Colic Scale.

Table 3
Bivariate Correlations^a among NIDCAP® Behaviors and HRV Indices at 1 Week, and ICS at 6–8 Weeks (N = 30)

Measure	1 lnLF (ms ²)	2 lnHF (ms ²)	3 Total Power (ms ²)	4 lnLF/lnHF Ratio	5 Total Stress Behaviors	6 Self- Consoling Behaviors	7 ICS Total Colic Score	8 Type of Feeding at d/c
1. lnLF(ms ²)	--							
2. lnHF(ms ²)	.88**	--						
3. Total Power(ms ²)	.99**	.91**	--					
4. lnLF/lnHF Ratio	.24	-.21	.15	--				
5. Total Stress Behaviors	.41*	.16	.35	.44*	--			
6. Self-Consoling Behaviors	.61**	.49**	.60**	.30	.52**	--		
7. ICS Total Colic Score	-.11	-.15	-.14	-.04	.02	-.17	--	
8. Type of Feeding at Discharge	.43*	.33	.42*	.14	.15	.14	.16	--

Notes:

^a Bivariate correlations were done using Spearman correlation coefficients.

NIDCAP® = Neonatal Individualized Developmental Care and Assessment Program, ICS = Infant Colic Scale, lnLF = natural log of low frequency HRV, lnHF = natural log of high frequency HRV. Types of Feeding at Discharge were coded as: 0 = exclusively formula fed, 1 = formula and breast milk fed, and 2 = exclusively breast milk fed. N = 19 for correlations with colic score.

* $p < .05$;

** $p < .01$