Cardiorespiratory Reactivity During the Brazelton Scale in Term and Preterm Infants

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Determined the relationship between behavior measured with the Brazelton Scale and simultaneously recorded cardiorespiratory activity. The Brazelton Scale was administered and videotaped in a sample of 22 term and 22 preterm infants at term conceptional age. The videotapes were coded off line with a computer interface to time lock behavior and physiological activity for the duration of four alert, non-crying conditions. Term infants showed increases in heart rate and breathing rate when unswaddled and cuddled following cry and increases in respiratory sinus arrhythmia (RSA) during orientation and swaddling. Preterm infants showed the same general trend as term infants in heart rate and breathing rate. However, RSA decreased during orientation in preterm infants. On behavioral scores, preterm infants showed lower scores on self-regulation and a higher cost of attention. Correlations between behavior and physiological activity showed lower RSA associated with enhanced behavioral scores for the preterm infants. Results of this study are consistent with the hypothesis that attentional responsivity in the preterm infant may be at the expense of physiological stability.

KEY WORDS: preterm; infant; cardiorespiratory; Brazelton Scale.

One of the problems in studying psychological constructs in the newborn is to identify behavior that is sufficiently mature to provide meaningful data, that is, what response system to measure. This problem becomes more complicated

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when high-risk infants, such as those born prematurely, are involved. Heart rate has been a popular measure, in part because the cardiovascular system is well developed, in term as well as in preterm infants. Heart rate can be detected from approximately the 4th week after conception and both sympathetic and parasympathetic systems are operative by term. The clear presence of respiratory sinus arrhythmia (RSA), heart rate variability due to the influence of breathing rate, in the full-term infant indicates a definite cardiorespiratory coordination by well-known brain structures. This respiratory–heart rate coupling, mediated by the vagus, has been clearly demonstrated in the preterm infant by 36–37 weeks gestational age and reflects a transition from sympathetic to parasympathetic dominance occurring during the postnatal period (see Porges, 1986; Porges, McCabe, & Yongue, 1982).

In the late 1970s and early 1980s most of the work involving heart rate was based on Sokolov’s concept of the orienting response (Sokolov, 1963), a central nervous system (CNS) mechanism that enhances the processing of information in all sensory systems. Graham and Clifton (1966) following work by Lacey with adults (1956), made the link between cardiac deceleration as a measure of sustained attention and cardiac acceleration as a defensive response in infants and much effort has been devoted to trying to answer the question, “Can cardiac orienting be demonstrated in the newborn?” This question had, and still has, profound developmental implications for the emergence of cognitive and learning capabilities and in terms of our understanding of the development of brain systems responsible for relatively high levels of attentional behavior.

It is now three decades later and there are a number of studies that suggest that the newborn is capable of the cardiac orienting response but, as Berg and Berg (1979) pointed out, the newborn does so with great reluctance. The response can be elicited only when rather stringent conditions are placed on the infant; the most important condition being state—a necessary condition to elicit cardiac orienting is that the infant is in a quiet alert state.

A related line of research also reported relationships between heart rate variability and attention. Porges, Arnold, and Forbes (1973) reported that infants with higher resting levels of heart rate variability were more likely to show the cardiac orienting response. Further, Porges and associates worked to quantify heart rate variability, specifically the component of heart rate variability due to breathing or RSA. The amplitude of RSA is thought to provide an index of vagal tone or parasympathetic control of autonomic function (Eppinger & Hess, 1915; Porges, 1986). Moreover, increased respiratory arrhythmia or vagal tone is sometimes associated with sustained attention (Porges, 1986). Thus, we now have two approaches to the attention puzzle: heart rate deceleration and changes in RSA.

However, the cardiovascular system does more than reflect attentional processes. The primary function of the cardiovascular system is not to reflect atten-
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We know from the work of Obrist (1976) and others that changes in somatic activity influence cardiorespiratory activity and need to be considered when using heart rate as a measure of attention. Although there is an inherent cardiosomatic coupling, cardiorespiratory changes associated with attention can still be detected against a background of somatic influences on heart rate. Heart rate then, reflects and integrates "vegetative state" or metabolic needs, as well as activation of attentional. The exciting question then becomes, under what conditions or circumstances can external stimuli, attention-getting stimuli, or stimuli that activate the attention system, compete with internal or somatic stimuli for control of the heart. Or, to put it another way, when does the attention system override or preempt the metabolic system? Are some infants better able to regulate this balance between internal and external demands than others? For example, how would the preterm infant under cardiorespiratory stress handle these demands as compared with the healthy term infants?

Eliciting sustained attention in the newborn requires manipulation of the infant's state which can be accomplished systematically in the context of the Neonatal Behavioral Assessment Scale (Brazelton, 1984). The Brazelton Scale is usually used as an instrument that elicits and evaluates the full range of newborn behavior. However, the scale can also be used as a methodology to elicit behavior episodes including states that can then be used to study other developmental questions. Here the scale becomes a methodology in which the examiner becomes the independent variable, the experimental condition, if you will, to elicit and maintain behaviors or behavioral episodes of interest. One example is to study the relationship between behavior and physiological activity as shown in Figure 1.

The upper grid in Figure 1 shows each of the Brazelton Scale states and events performed by the examiner. Shaded boxes indicate when an event or state has occurred. This information is coded from videotape with a computer interface. EKG and respiration are recorded simultaneously with telemetry and the computer interface time locks and shows the physiological activity concurrent with behavior. Physiological activity during the scale is shown in the lower panels. The bottom panel is the amplitude of respiration, followed by breathing rate, heart rate, and vagal tone. Vagal tone is measured on a log scale. In healthy term infants during sleep, vagal tone averages 3.8–4.0 with a standard deviation of about 1.0–1.2. Since physiological activity is measured during the Brazelton we can use the time line analysis on the top to define behavioral episodes or conditions of interest to study how physiological activity changes as different behaviors are elicited from the infant. The purpose of this study was to relate behavior and physiological activity in term and preterm infants. We used the time-line analysis approach to study cardiorespiratory activity (heart rate, RSA, and breathing rate) during episodes of the Brazelton Scale in term and preterm
infants and to relate cardiorespiratory activity to summary Brazelton Scale scores.

METHODS

Participants

The sample included 22 healthy term infants and 22 preterm infants, born on the average at 28 weeks gestational age with a mean birth weight of 1,103...
Table I. Preterm Sample Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birthweight</td>
<td>1,103</td>
<td>278</td>
<td>570</td>
<td>1,720</td>
</tr>
<tr>
<td>Gestational Age</td>
<td>28</td>
<td>2</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>Apgar 1</td>
<td>5</td>
<td>1.9</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Apgar 5</td>
<td>7</td>
<td>1.8</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Days Hospitalized</td>
<td>78</td>
<td>25</td>
<td>25</td>
<td>137</td>
</tr>
<tr>
<td>Hollingshead SES</td>
<td>2.6</td>
<td>1.1</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
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grams. Table 1 shows sample characteristics of the preterm infants. The preterm infants had been sick with respiratory disease, all had been on mechanical ventilation, and averaged 78 days hospitalization. The term and preterm infants were tested on the Brazelton Scale with physiology at term or 40 weeks gestational age.

Procedure

We defined four conditions based on the time-line analysis and measured physiological activity within each condition. The four conditions were all alert, noncrying conditions. In the first condition, the infant was swaddled and left alone and no responses were elicited from the infant. The second condition was during the orientation condition in which the examiner attempted to elicit sustained attention (e.g., tracking the red ball, with the infant in a quiet alert state). The third condition was similar to the first condition except that the infant was not swaddled; that is, alert, not crying, and no responses were being elicited. In the last condition, the infant was being cuddled in the examiners arms following consoling due to crying. The infant had stopped crying and was alert.

RESULTS

Physiological Findings

Physiological activity was computed as a mean for each of the four behavioral conditions. Statistical significance was tested using a 2 (Group: term, preterm) × 4 (Condition: swaddle, orientation, unswaddle, cuddle) repeated measures analysis of variance. Following statistically significant F tests, mean differences were tested with the Duncan test and are reported below.

Figure 2 shows the mean heart rate and breathing rate (left ordinate) and RSA (right ordinate) during the four behavioral conditions for the group of term...
infants. For term infants, heart rate was not significantly different during swaddling and orientation but significantly increased ($p < .05$) when the infant was unwrapped and cuddled. The change in heart rate across the four conditions was about 13 beats per minute (from 128 to 141). Breathing rate dropped slightly across the four conditions. There was a 4-breath per minute change (39–43) over the four conditions. RSA was significantly higher ($p < .05$) in the swaddling and orientation conditions than in the unwrapped and cuddle conditions. When RSA was converted to heart rate variance, in other words, expressed as the standard deviation of heart rate, these differences represented a 15-beat per minute change in heart rate variance or beat to beat heart rate variability. This means that RSA, vagally mediated oscillations in heart rate associated with breathing, or cardiorespiratory coupling, was highest when infants were quiet alert and swaddled or when the attentional system was activated following the orientation condition. When these infants were unwrapped or cuddled following soothing there was an increase in heart rate and a reduction in heart rate variability.

Figure 3 shows heart rate, breathing rate, and RSA for the same four conditions in the preterm infants. The preterm infants showed a different pattern of results even though they were tested at the same gestational age as the term infants. As these were preterm infants with respiratory problems, it is understandable that heart rate was higher (range here is from 153–161, $p < .05$) and breathing rate was higher (range is 46–53, $p < .05$) than the term infants. In addition, RSA was lower in the preterm infants than in the term infants ($p < .05$). The preterm infants showed the same general trend as did the term infants.
in heart rate and breathing rate across the four conditions. Heart rate increased ($p < .05$) and breathing rate decreased ($p < .05$) from the swaddle condition to the cuddle condition. However, RSA in the preterm infants was significantly lower during the orientation condition than during the other conditions ($p < .05$). When RSA is converted to heart rate variance, the variability in heart rate is only 6–9 beats per minute change across the different conditions in contrast to the 15–30 beats per minute in heart rate variance shown in the term infants.

Results of the physiological finding in the term infants are consistent with our expectations for a group of well-organized healthy newborns in showing the dual nature of the cardiorespiratory system and the idea that attention can compete with somatic demands for control of cardiac processes. Activation of the attention system during the Brazelton Scale, when the infant is left to scan the environment, helped by swaddling, or when challenged with specific attention getting stimuli during orientation, overrides somatic demands resulting in physiological responses that facilitate or enhance stimulus intake.

By contrast, the preterm infants showed their lowest RSA when challenged with attention-eliciting stimuli during the orientation sequence. In these infants formerly with respiratory problems the cardiorespiratory system was already taxed and they could not override somatic demands when challenged with attention getting stimulation. These infants have a higher baseline heart rate and breathing rate and less RSA to attentional demands. External attention-getting stimuli cannot compete with internal somatic demands suggesting less enhancement or facilitation of stimulus intake at the physiological level.
Behavioral Results

These physiological results invite consideration of the relationship between the Brazelton Scale behavioral scores and the physiological findings. We found no significant differences in mean scores on the orientation cluster or on the quality of attention supplementary score between term and preterm infants. However, we did find statistically significant differences between term and preterm infant supplementary scores that relate to the infant's ability to regulate input from the environment.

Preterm infants showed lower scores on self-regulation ($p < .05$) and they showed a higher cost of attention ($p < .05$) than the term infants. In other words, one can elicit, at the behavioral level, relatively high levels of attentional responsiveness in the sick preterm infant. The levels are comparable to term infants at the same conceptional age and are shown in both quantitative and qualitative measures of attention. However, these high levels of attention in the preterm infant are disruptive at the behavioral level, self-regulation is compromised and there is a higher cost of attention and physiologically, they show less RSA.

Correlations Between Behavioral Scores and RSA

Insights into individual differences in how the preterm infants responded to attentional demands are shown by examining statistically significant correlations between Brazelton supplementary behavior scores and RSA.

Preterm infants with better regulation scores showed less RSA (Figure 4, $r = -.42$). Infants with better control over input (stimulation) from the environ-

![Fig. 4. Relationship between vagal tone and regulation in preterm infants.](https://academic.oup.com/jpepsy/article-abstract/21/6/771/908977/fig4.png)
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Fig. 5. Relationship between vagal tone and control over input in preterm infants.

Infants who showed more robustness during the exam, that is, they had more energy resources, also showed less RSA (Figure 5, $r = -0.51$). Less RSA was also correlated with a higher quality of attention (Figure 7, $r = -0.38$). In other words, "better" behavioral scores in the preterm infants, that is higher levels of regulatory abilities, were seen in infants with less heart-rate variability, suggestive of less cardiorespiratory coupling and a loss of parasympathetic control. Higher levels of behavioral responsivity in these preterm infants were at the expense of physiological stress, or there is a physiological cost to higher levels of behavioral function in preterm infants with respiratory problems. For the group of term infants, there were no statistically significant correlations between Brazelton supplementary scores and RSA.

Fig. 6. Relationship between vagal tone and robustness in preterm infants.
DISCUSSION

The results from this study suggest that the healthy term infant is capable of handling the combination of internal, somatic plus external, especially attentional demands. When challenged by attentional demands, be it passive attention, as when swaddled and left alone, or active attention during the orientation condition, activation of the attention system preempts the cardiac somatic relationship and results in increased parasympathetic control or coupling of cardiorespiratory activity. This in turn facilitates stimulus intake and enhances information processing.

The preterm who is already under cardiorespiratory stress has a much more difficult time trying to balance internal metabolic demands with attentional demands. We can activate the attention system in these infants and they are responsive. However, the attentional system cannot compete with the metabolic system and cannot override the somatic demands to control cardiac processes to facilitate information processing. Rather, we see increased somatic demands, a loss of parasympathetic control and less coordinated cardiorespiratory effort. Attentional responsivity can be achieved in these infants but at the expense of physiological stability. Moreover, active attentional demands (orientation condition) seem to be more demanding for these infants, physiologically, than passive attention, when attention is not elicited.

We do not know the consequences of this pattern of physiological reactivity in the preterm infant. It is possible that this type of physiological reactivity in the preterm could be adaptive and serve to regulate the level of input that the infant can tolerate or protect the infant from overstimulation. It may be that it is only with increased somatic demands that these infants can respond behaviorally; that
the only way they can show attentional responsivity is through some loss in physiological stability.

In a preliminary study using the same methodology as in the present study but with a different sample of infants, we (Lester et al., 1990) found that preterm infants showed less change in heart rate deceleration and RSA than term infants during orientation on the Brazelton Scale and that RSA during orientation on the Brazelton Scale was significantly correlated with Bayley MDI \( r = .44 \) and PDI \( r = .45 \) scores at 8 months. Our previous findings and the results of the present study support the models suggested by Field (1981), and Tronick, Scanlon, and Scanlon (1990). Field (1981) proposed a general activation band hypothesis based on a review of the literature on early interactions that included behavioral and psychophysiological findings. According to this model, attention and positive affect occur within a range or band of activation with an attention threshold at the lower limit in which stimulation is accepted and an aversion threshold at the upper limit in which stimulation is rejected. Biological insult such as prematurity may result in a narrower band, that is, a higher attention threshold and a lower aversion threshold.

Tronick et al. (1990) reported descriptive data on the behavioral organization of extremely low birth weight infants during the acute and early recovery phases from cardiorespiratory illness. These infants were inactive, unresponsive, and mostly in sleep states. They suggested that this form of behavioral organization may be a protective apathy that aids recovery by enabling the infant to conserve energy and maintain homeostasis, somewhat akin to the classic notion of the stimulus barrier as a protective mechanism (Freud, 1965). Tronick et al. further suggested a paradoxical reactivity hypothesis, in which preterm infants have a high stimulus threshold and a low defensive reaction threshold, which makes them appear hyporesponsive except when the stimulus is strong enough to cross their stimulus threshold, in which case they appear hyperreactive.

Preterm infants are often described as easily overwhelmed by stimulation (Lester & Tronick, 1990). The results from the present study are consistent with the hypothesis that one physiological reaction to excessive or inappropriate stimulation is a central or sympathetic nervous system response that blocks the vagal inhibition that would result in cardiac deceleration and increased RSA. Such a mechanism could provide evidence for the stimulus barrier which prevents stimulation from overloading neural circuits, and helps the infant maintain homeostatic balance. Rather than a deficit in information processing this interpretation views the physiological findings as an adaptive response that prevents the infant from being at the mercy of stimulation that is above the aversion threshold but could attenuate information processing and learning.

Our findings also raise questions about the meaning of behavioral and cardiorespiratory measures in term and preterm infants. Had we relied solely on
behavioral findings we would have concluded that term and preterm infants showed similar levels of attention during the orientation sequence of the Brazelton Scale. If the preceding physiological hypothesis is correct it may be that infants who show both behavioral and physiological evidence of stimulus intake are, in fact, processing stimulation at the CNS level as shown by the term infants in this study. Infants who show behavioral but not physiological evidence of attention, may be rejecting the stimulus at a CNS level as shown by the preterm infants. Thus, for an individual infant, the interpretation of a behavioral measure of attention may depend upon the accompanying physiological response.

This study shows the complementarity of behavior and physiological activity. The study of simultaneous changes in behavior and physiological may provide markers for the integration of developmental processes that are less apparent when behavior and physiology are studied independently.

From a clinical perspective, the fact that physiological stress is increased during interaction may want to make us think more carefully about how much we want to promote social interaction in the preterm infant. We may want to facilitate passive attention more than active attention. We may want to rethink how hard we want to push parents and hospital staff to engage these infants in active interaction. Parents' expectations have already been violated by having a preterm infant and they look forward to taking home a socially responsive baby. We may need to work more with parents to determine the kind of interaction that is best suited for the individual infant.

From an assessment point of view, we suggest that it would be useful to include measures of physiological reactivity as part of the behavioral assessment of the preterm infant and that behavioral responsivity should be interpreted in the context of physiological responses. This would have both an impact on the management of the preterm infant while in hospital and at home. In our hospital, we find it useful to have the parents present when we conduct the Brazelton assessment with physiological monitoring and we discuss with the parents how their infant responds both behaviorally and physiologically. In this way, the Brazelton Scale becomes the context in which the complementarity of behavioral and physiological activity can be used to foster the parent-infant relationship.

REFERENCES


