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Baseline respiratory sinus arrhythmia and heart rate responses during sustained visual attention in preterm infants from 3 to 6 months of age

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Abstract

Three groups of preterm infants were studied longitudinally at 14, 20, and 26 weeks of age (corrected for gestational age). The groups included infants with no perinatal medical complications, those with mild respiratory problems requiring ventilatory assistance, and those with respiratory distress syndrome. Baseline heart rate and respiratory sinus arrhythmia (RSA) were recorded for 5 min, and heart rate was also recorded while the infants engaged in sustained visual attention to stimuli presented on video monitors. The heart rate response during stimulus orienting and sustained attention was smaller in those infants with respiratory distress syndrome than in the other preterm infants and in comparison with the response seen in full-term infants in previous research. Magnitude of RSA was positively correlated with the attention responses irrespective of the preterm group assignment. There was greater stability in baseline heart rate and RSA for the preterm infants than has been found with full-term infants. These data suggest that the cardiorespiratory functioning of the preterm infant indexes a stable individual difference characteristic that is correlated with heart responses during sustained attention, and heart rate attention systems may be damaged in the high-risk preterm infant.

Descriptors: Infant heart rate, Respiratory sinus arrhythmia, Preterm infants, Respiratory distress syndrome, Sustained attention

The heart rate responses of preterm infants during attention differ from those of normal full-term infants. The response may be weaker (Bench & Parker, 1971; Berkson, Wasserman, & Behrman, 1974; Rose, Schmidt, & Bridger, 1976; Schulman, 1970b) and often fails to habituate with repeated stimulus presentation (Field, Dempsey, Hatch, Ting, & Clifton, 1979; Fox & Lewis, 1983; Schulman, 1970a). Some studies have shown that preterm infants with likely central nervous system damage, or with respiratory distress syndrome (RDS), have unusual heart rate responses during attention (Fox & Lewis, 1983; Schulman, 1970b). For example, Fox and Lewis (1983) and O'Connor (1980) found that at 3 or 4 months "conceptional" age (gestational age + postnatal age), full-term and healthy preterm infants showed similar heart rate orienting, habituation, and response recovery to an auditory stimulus. However, preterm infants with RDS did not show response habituation or response recovery to a novel stimulus. Preterm birth by itself may not necessarily result in an attenuated heart rate response during attention. Rather, compromising medical events in the perinatal period associated with preterm birth may be what affect the infant's attention system. The present study examined the heart rate responses during attention of low- and high-risk preterm infants.

Behavioral measures of attention are also unusual in preterm infants with perinatal medical complications. Of particular interest are some studies of attention to toys by high- and low-risk infants. Preterm infants with perinatal medical problems, as compared with low-risk preterm infants and full-term infants, engage in less toy exploration and engagement at 6 months of age (Landry, 1986), show fewer shifts in looking at toys, notice fewer toys, and examine toys less (Landry & Chapieski, 1988). Ruff (1986; Ruff, McCarton, Kurtzberg, & Vaughan, 1984) used object examination as a measure of focused attention because it involves the active intake of stimulus information. Six-month-old preterm infants spent less time in object examination than did full-term infants. Nine-month-old low-risk preterm infants did the same amount of object examination as did full-term infants, whereas high-risk infants continued to show depressed amounts of time engaged in object examination. The finding of

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differences between full-term and preterm in focused attention rather than other attention types implies that preterm/full-term differences are not the same over all attention types. Ruff's studies suggest that initial differences between low-risk preterm infants and full-term infants may be transitory, whereas infants with perinatal medical difficulties may have deficits in attention that continue throughout infancy.

Because both heart rate and behavioral responses to stimuli are affected in preterm infants, both measures can be examined simultaneously to study different types of attention. A procedure could be used whereby different phases of attention are defined by heart rate changes related to fixation on a visual stimulus. The heart rate changes during attention of full-term infants have been used to distinguish the infant's initial reaction to a stimulus (stimulus orienting), focused attention to the stimulus (sustained attention), and disengagement of attention from the stimulus (attention termination) (Graham, 1979; Graham, Anthony, & Zeigler, 1983; Porges, 1976, 1980, 1992; Richards, 1988; Richards & Casey, 1991, 1992). These attention phases are associated with distinctive heart rate responses and behavioral activity. For example, visual sustained attention is characterized by a sustained lowered mean heart rate, lowered heart rate variability, and lack of distractibility from central stimulus fixation in the presence of a peripheral stimulus (Richards, 1987; Richards & Casey, 1991, 1992). Because preterm infants' heart rate and behavior in attention-eliciting situations are different from those of full-term infants, the combination of the heart rate-defined attention phases and behavioral measures may elucidate the problems that occur in preterm infants' attention.

There were three goals of the present study. The first goal was to evaluate preterm infants' heart rates and behavioral responses from 14 to 26 weeks of age (corrected age) during stimulus orienting, sustained attention, and attention termination. Preterm infants' abnormal heart rate responses may result in unusual attention phases defined by the heart rate change. For example, if the high-risk preterm infant's heart rate response is attenuated, the full sequence of attention phases (stimulus orienting, sustained attention, attention termination) might not occur properly. The heart rate response should be diminished in preterm infants who had RDS in the perinatal period as compared with other groups of preterm infants who are at low risk for poor outcome because of milder perinatal difficulties or as compared with full-term infants with healthy postnatal medical histories.

A second goal of the study was to relate the infants' attention responses to their risk status, defined by perinatal events, and their concurrent respiratory sinus arrhythmia (RSA) magnitude. Baseline RSA magnitude correlates with heart rate responses and behavioral activity in attention in full-term infants from 14 to 26 weeks of age. Preterm infants, especially high-risk infants with respiratory disorders such as RDS, as a group have lower RSA than do full-term infants or preterm infants with few medical problems (Fox, 1983; Kero, 1973; Rother et al., 1987). Because RSA indexes individual differences in sustained attention in full-term infants, the depressed RSA magnitude in preterm infants should parallel their attention deficiencies. The expected low RSA in these preterm infants also should expand the range of individual differences in RSA level compared with past research with full-term infants (e.g., Richards, 1987). Thus, the relation between individual differences in sustained attention and individual differences in RSA level would cover a broader range of both RSA and attention. Infants who had perinatal respiratory difficulties and those with concurrent abnormally low RSA should show attention responses different from those of low-risk preterm infants and full-term infants.

The third goal was to examine the stability of baseline heart rate measures and the stability of the responses during attention across 14–26 weeks of age in preterm infants. Both Porges (1976, 1980, 1992) and Richards (Richards, 1988; Richards & Casey, 1992) have hypothesized that individual differences in RSA are related to individual differences in sustained attention. Individual differences in RSA or sustained attention (Ruff, 1990; Ruff, Lawson, Parrinello, Weissberg, 1990) should result in similar patterns of attention or RSA within individuals across this age range. Preterm infants, who may have damaged cardiorespiratory control, may show attenuated RSA and corresponding poor attention that are stable across age. Stable heart rate measures (e.g., mean heart rate, RSA) and stable attention responses should show a parallel between the individual differences in these measures in full-term infants and the group differences for the preterm infants.

Visual attention, heart rate, and RSA were measured in preterm infants tested in a longitudinal design at 14, 20, and 26 weeks of age (corrected for gestational age). The ages were the same as in previous studies with full-term infants (e.g., Richards, 1987, 1989) and show parallel developmental changes in RSA and sustained attention (Richards, 1989). Three preterm groups were defined according to perinatal respiratory status: no respiratory complications, ventilatory assistance without continued respiratory difficulties, and respiratory distress syndrome. Additional data from a previous study using full-term infants (Richards, 1989) were also used. Visual attention was measured in a procedure that was a replication of the study by Richards (1989) in which full-term infants were tested. A central stimulus was presented until the infant fixated upon it, and at some delay a peripheral stimulus occurred to distract the infant's fixation from the central toward the interrupting stimulus. Active central stimulus processing coincides with lack of distractibility by the peripheral stimulus. Sustained lowered heart rate (sustained attention) should occur with longer delays of distraction, whereas the return of heart rate to prestimulus levels (attention termination) should be associated with short distraction times. Behavioral (distractibility) and physiological (sustained lowered heart rate) sustained attention indices should be complementary tools for assessing sustained attention.

Methods

Subjects

Thirty-four preterm infants were recruited from birth notices and advertisements in a Columbia, SC, newspaper and from pediatrician referrals. The preterm infants were defined as having birth weights less than 2,500 g and gestational age of 37 weeks or less determined by the mother's report of her last menstrual cycle. A longitudinal design was used to sample infants at conceptional ages (gestational age + postnatal ages) of 54, 60, and 66 weeks. These ages correspond to the 14-, 20-, and 26-week-old ages for full-term infants. Testing was done only if the subjects maintained an alert, awake state during the entire procedure (eyes open, no fussing or crying, responding to the protocol). Five subjects at 54 weeks did not maintain this state during testing and were tested again in the same week. An additional four subjects dropped out of the study before completing the three testing sessions and were not included in the analyses.

The preterm infants were classified into three groups. *No respiratory complications* preterm infants had only minor perinatal medical complications (e.g., treated hyperbilirubinemia) and no respiratory complications and had uneventful pediatric histories. *Ventilation assistance* preterm infants had at least 24 hr of ventilation assistance during the neonatal period. Ventilation assistance was given for low Apgar scores, breathing difficulties, or apnea episodes. Ventilation assistance preterm infants had otherwise uneventful neonatal or pediatric histories. *Respiratory distress syndrome* preterm infants had significant respiratory difficulties at birth, including RDS and asphyxia (all these infants received extended ventilatory assistance). Preterm infants with perinatal or postnatal medical complications other than respiratory were excluded from the study. Table 1 presents the gestational ages, birth weights, sex, 6-month (corrected for gestational age) Bayley Developmental Exam scores, and numbers of subjects in each group.

Data from 28 full-term infants from a previous study (Richards, 1989) were used in some of the comparisons reported below. The full-term infants had birth weights greater than 2,500 g and gestational ages greater than 38 weeks. The full-term infants had no perinatal or pediatric medical complications.

Apparatus

The infant was held in its parent's lap in front of a black and white TV monitor (49 cm [19 in.]). The primary stimuli were patterns shown on the TV monitor (recording of a Sesame Street TV program or computer-generated patterns). All stimuli were presented in a 30-cm^2 area, subtending approximately 32° visual angle. The stimuli for the interrupted stimulus trials consisted of two 17-cm × 11-cm panels that had 20 LEDs that blinked on and off at 16 Hz in a sequential pattern resembling a circle. The panels were located 42 cm (38°) to either side of the center of the screen.

Procedure

Respiration and the electrocardiogram were recorded for a 5-min period during which the infant was seated on the parent's lap on a couch. The parent was then seated in the chair with the child on the lap facing the monitor. The LED panels were presented for four trials to acquaint the infant with their location. Each trial consisted of a 5-s period with no stimulus followed by the presentation of an LED panel. The panel remained on as long as the infant was looking at it, up to a maximum of 15 s.

Table 1. *Subject Characteristics*

	Preterm risk groups			
	No respiratory complications	Ventilation assistance	Respiratory distress syndrome	Full term
Gestational age	34.1	31.8	32.5	>38
Birth weight (g)	2,102	1,787	1,806	3,533
Sex (M, F)	8, 7	6, 3	7, 3	16, 12
Bayley MDI	121.4	121.5	128.2	127.1
Bayley PDI	120.0	118.7	120.4	114.8
n	15	9	10	28

The experimental trials consisted of four infant control trials and eight interrupted stimulus trials. The infant control trials consisted of the presentation of the primary stimulus until the infant looked away from it. The interrupted stimulus trials consisted of the presentation of the primary stimulus followed by the presentation of one of the secondary stimuli at a delay from the onset of visual fixation on the primary stimulus. When the infant looked away from the primary stimulus to the secondary stimulus, the primary stimulus was discontinued and the secondary stimulus remained on for 5 s.

The time of the secondary stimulus onset was based on one of the following criteria: (a) 3 s – presented when 3 s had elapsed; (b) 7 s – presented when 7 s had elapsed; (c) heart rate deceleration – presented when a significant cardiac deceleration had occurred; (d) heart rate acceleration – presented when heart rate began to return to the prestimulus level following a cardiac deceleration. A cardiac deceleration was defined as five successive beats with an R-R interval longer than the median interval of the five heart beats preceding the presentation of the primary stimulus. The return of heart rate to the prestimulus level was defined as five successive beats with an R-R interval shorter than the median interval of the five prestimulus heart beats and must have followed a deceleration. The trials on which secondary stimulus onset were defined by heart rate were restarted if a deceleration did not occur within 10 s of fixation onset. Interrupted stimulus trials were restarted if the infant looked away before the interrupting stimulus onset. The percentage of restarted trials for no cardiac deceleration was 32%, 22%, 23%, and 21% for the no respiratory complications, ventilation assistance, and respiratory distress syndrome groups and full-term infants, respectively; the percentage of restarted trials for looking away was 12%, 11%, 11%, and 8%, respectively. Two six-trial blocks were used, each with two infant control trials and one trial from each of the four types of interrupted stimulus criteria, with procedure order randomly chosen within each six-trial block.

Quantification of Physiological Variables

The electrocardiogram was recorded by placing Ag-AgCl electrodes on the infant's chest with disposable electrode collars. Beat-to-beat intervals were computed on-line with a microcomputer by identifying the R-wave of the electrocardiogram and measuring R-R intervals with 1-ms resolution. The evaluation of cardiac deceleration and return to prestimulus levels during the trials was done with programs that made the evaluation within 1 ms of the criterion beat. For quantitative analyses, the beat-to-beat R-R intervals were converted to rate (bpm) by assigning values to equal intervals based on the number of beats in the interval weighted by the proportion of time that the beat occupied the interval. The interval duration to which heart rate values were assigned was 100 ms for the baseline period (0.1 s × 0.1 s) and 500 ms for the experimental trials (0.5 s × 0.5 s) (see Graham, 1978). Rate rather than period was chosen as the cardiac function to coordinate the heart response with fixation in the experimental trials (Graham, 1978; Richards, 1980).

Respiration was measured during the baseline period with a pneumatic chest cuff, and a pneumatic respiration transducer (Grass Instruments) quantified thoracic circumference changes due to respiration. The respiration signal was digitized on-line at 50 Hz by a microcomputer. Respiration frequency was quantified for each baseline minute by detecting the number of breaths that occurred in each minute. Respiration frequency was quantified only for the baseline period to determine the modal respiration frequency for respiratory sinus arrhythmia quantification.

Respiratory sinus arrhythmia was computed with spectral analysis methods from the baseline recording. The 0.1-s × 0.1-s heart rate series was first detrended with a band-pass filter that was designed to pass the frequencies associated with infant respiration (Porges, 1985; Richards, 1986). The RSA magnitude was defined as the power of heart rate summed over a frequency range of 0.1953 Hz (11.71 breaths/min) and centered at the modal respiration frequency for that baseline period (Richards, 1986, 1987; cf. Harper et al., 1978, and Porges, McCabe, & Yongue, 1982). This power measure was transformed by the natural logarithm function for the data analysis. The metric for RSA is the natural logarithm of the root-mean-squared variation of heart rate at the respiration frequency ranges. The first 512 0.1-s intervals of each minute were used, giving a frequency resolution of 0.01953 Hz. The value was extracted separately for each period and was averaged over the 5 baseline minutes.

Experimental Design for Statistical Analysis

The results were analyzed in a factorial design. Testing age, procedure (heart rate deceleration, heart rate acceleration, 3 s, 7 s), and intervals (0.5-s × 0.5-s period) were within-subjects variables. Risk group (no respiratory complications, ventilation assistance, respiratory distress syndrome) was a between-subjects variable. The data from the infant control trials were not analyzed. Post hoc comparisons were done using the Scheffé test to control experimentwise error rate. The trials variable (two six-trial blocks) was not directly relevant to the study and was not analyzed. For the intervals effect, only the variation due to the linear, quadratic, and cubic trends was analyzed, because often only the lower order trends are of interest or are interpretable in the context of heart rate research. The statistical significance of the intervals effect was based on the multivariate approach to testing repeated measures (McCall & Appelbaum, 1973; O'Brien & Kaiser, 1985), because repeated physiological measures may violate some assumptions of the univariate analysis of variance (ANOVA) procedure. Because the response form for the intervals data is important, only those effects interacting with the intervals variable were tested.

Data for full-term infants were collected, and some results were reported in a previous study (Richards, 1989). These subjects were tested at the same ages, in the same paradigm, and longitudinally. Some of the results in the present paper include data from the full-term infants to provide quantitative comparisons between the full-term and preterm samples.

In previous research with full-term infants (e.g., Richards, 1987, 1989), the extent of RSA was used as a categorical variable for attention analyses by performing a median split within each age on the continuous RSA measure and separating subjects into low- and high-RSA groups. However, the preterm infants as a group were expected to have lower RSA than the full-term infants. Thus, the absolute RSA magnitude should be used for comparing prior results with full-term infants. To make a categorical variable consistent with this, the following procedure was used. The RSA levels for the full-term infants from the three ages were combined to make an average Z score, and a median split was used to classify the full-term infants into low- and high-RSA groups. The preterm infants were classified into three groups based on their RSA relative to the full-term infants: (a) RSA lower than that of any full-term infant; (b) RSA below the full-term infants' median RSA at same corrected age; (c) RSA above the full-term infants' median RSA at same corrected age. These three groups were used as a categorical variable in the analysis of the attention responses.

Results

Baseline Heart Rate and Respiratory Sinus Arrhythmia

The mean of the baseline 0.1-s × 0.1-s heart rate values, the standard deviation of those values, and the magnitude of respiratory sinus arrhythmia were analyzed with a one-way repeated measures ANOVA with an Age (3) × Preterm/Full-Term Groups (4) factorial design. Mean heart rate and the standard deviation of heart rate were significantly affected by age ($ps < .05$). Across the three testing ages, there was a decline in mean heart rate and the standard deviation of heart rate (Table 2). The preterm/full-term variable significantly affected the standard deviation of heart rate, $F(3,178) = 13.24$, $p < .01$, and respiratory sinus arrhythmia, $F(3,178) = 35.48$, $p < .01$. Post hoc tests for both variables showed significant differences between the full-term and the three preterm groups, but the three preterm groups did not differ among themselves. The interaction between age and the preterm/full-term variable did not reach statistical significance.

As expected, the preterm infants as a group had lower RSA than did the full-term infants. Thus, absolute RSA magnitude should be used as the basis for comparing results for preterm infants with those for full-term infants. The preterm infants were classified into three groups: (a) RSA lower than that of any full-term infant; (b) RSA below full-term infants' median at same corrected age; (c) RSA above full-term infants' median at same corrected age. Table 3 shows the resultant distribution of subjects in each preterm risk group for this variable. The distribution of the categorical extent of RSA variable and preterm risk group were confounded. The no respiratory complications group had equal numbers of very low RSA, and low RSA infants, as did the RDS infants (Table 3). The ventilation assistance group had mostly low RSA infants. If the two low-risk preterm groups (no respiratory complications and ventilation assistance groups) were to be combined, their RSA level and distribution of very

Table 2. *Baseline Values for Subject Groups Across Testing Ages*

	14 weeks	20 weeks	26 weeks
Mean heart rate (bpm)			
Full term	152	148	142
No respiratory complications	159	150	145
Ventilation assistance	149	142	144
Respiratory distress syndrome	150	152	150
Standard deviation of heart rate			
Full term	13.3	13.2	11.3
No respiratory complications	10.0	9.5	9.5
Ventilation assistance	9.3	8.9	9.0
Respiratory distress syndrome	9.6	9.1	9.0
Respiratory sinus arrhythmia			
Full term	0.78	0.86	0.92
No respiratory complications	−0.16	−0.16	0.18
Ventilation assistance	0.44	0.51	0.78
Respiratory distress syndrome	−0.14	−0.20	−0.67

Table 3. *Number of Preterm Subjects in RSA Risk Categories*

	<Full term	Low RSA	High RSA
Full term	not defined	14	14
No respiratory complications	7	7	1
Ventilation assistance	0	7	2
Respiratory distress syndrome	5	5	0

low and low RSA groups would be intermediate between that of the RDS infants and the full-term infants.

Heart Rate Response of Preterm Risk Groups

The heart rate onset response was analyzed as the difference in the 0.5-s heart rate values during the first 5 s of the primary stimulus. This change score was analyzed with an Age (3) × Preterm Risk Groups (3) × Procedure (4) multivariate ANOVA (MANOVA), with the linear, quadratic, and cubic trends representing the intervals (10) as the multiple dependent variables. There was a significant interaction involving the intervals and procedures Wilks $\Lambda = .7774$, $F(9,323) = 3.92$, $p < .01$. The linear and quadratic polynomial trends accounted for this interaction ($ps < .05$). There was a large cardiac deceleration for all procedures. There were slight differences in the form of the deceleration for the four procedures.

There was a significant Preterm Risk Groups × Procedure × Intervals interaction, Wilks $\Lambda = .8002$, $F(18,376) = 1.71$, $p < .05$. The quadratic polynomial trend accounted for this interaction ($p < .05$). Figure 1 shows the heart rate onset response for the three preterm groups and the full-term groups for each procedure. Post hoc tests showed the heart rate deceleration procedure resulted in heart rate responses that were not significantly different for the three groups, possibly because of the criteria for a successful deceleration or repetition of the trial. For the other three procedures, the respiratory distress syndrome group had a smaller heart rate onset response ($ps < .05$). The response of the RDS group on these procedures had reached its maximum and was returning to prestimulus levels before the 5-s period had elapsed, whereas the other groups' heart rates were still decelerating. The deceleration for the no respiratory complications and ventilation assistance preterm groups was similar in form to that of the full-term infants.

The difference between mean heart rate during the 2.5-s period following the interrupting stimulus onset and the 2.5-s prestimulus mean was analyzed with an Age (3) × Preterm Risk Groups (3) × Procedure (4) ANOVA. The heart rate was analyzed from this period because it should index cognitive processing status at that moment and should complement the behavioral index of cognitive processing, distraction time. There was a significant procedure effect on the heart rate response, $F(3,93) = 22.10$, $p < .01$. As expected from the experimental manipulations, the heart rate on the heart rate deceleration trials was lower than that on the heart rate acceleration trials, with the 3-s and 7-s conditions having mean heart rate at intermediate levels. There was a significant Age × Preterm Risk Groups interaction effect on the heart rate response during this period, $F(4,51) = 2.57$, $p < .05$, and the interaction of age, preterm risk groups, and procedure approached statistical significance, $F(12,153) = 1.70$, $p = .0719$. Over the procedures, the no respiratory complications and ventilation assistance groups showed increasing heart rate responses over the three testing ages (no respiratory complications $Ms = -3.47, -3.89, -4.43$ bpm; ventilation assistance $Ms = -1.12, -3.90, -4.01$ bpm; for 14, 20, and 26 weeks, respectively). The RDS group had decreasing responses over these testing ages ($Ms = -2.8, -2.49, -1.89$ bpm, respectively). The post hoc tests for the three-way interaction showed that this effect was primarily due to the responses occurring in the heart rate deceleration procedure ($p < .05$). The full-term infants in this paradigm showed increasing responses

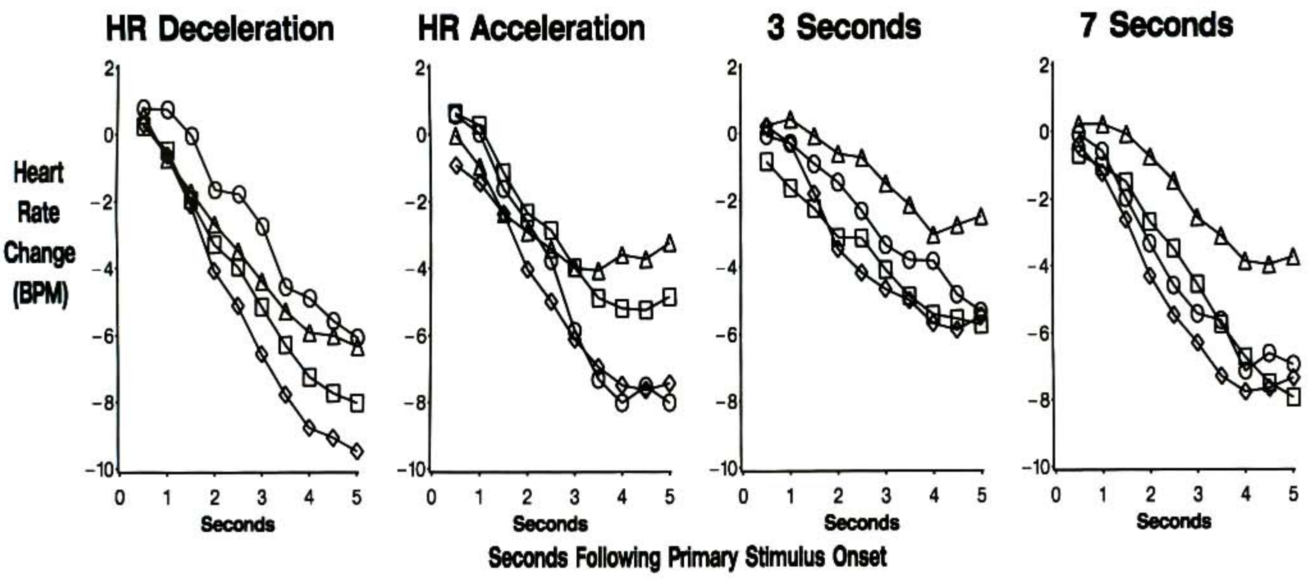

Figure 1. Mean heart rate change following the primary stimulus onset for the four interrupted stimulus procedures for the three preterm risk groups and the full-term infants. ◇ = full term; ○ = no respiratory complications; □ = ventilation assistance; △ = respiratory distress syndrome.

over the three testing ages (Ms = −8.9, −11.0, −11.62 for 14, 20, and 26 weeks, respectively).

The heart rate for the 2.5-s period preceding and following the interrupting stimulus onset was analyzed as the difference in the 0.5-s heart rate values during these intervals and the mean heart rate in the 2.5-s pre-primary stimulus period. This change score was analyzed with an Age (3) × Preterm Risk Groups (3) × Procedure (4) MANOVA, with the linear, quadratic, and cubic trends representing the intervals (10) as the multiple dependent variables. There were effects involving procedure and intervals that duplicated effects from past research, but these are not reported here. There were no effects that interacted with the preterm risk groups variable.

Heart Rate Response of Respiratory Sinus Arrhythmia Groups

The heart rate onset response was analyzed as the difference in the 0.5-s heart rate values during the first 5 s of the primary stimulus. This score was analyzed with an Age (3) × RSA Category (3) × Procedure (4) MANOVA, with the linear, quadratic, and cubic trends representing the intervals (10) as the multiple dependent variables. Only the interactions with RSA category were tested, because the other effects were reported in the previous section. Data from the full-term infants were included in the analysis to provide a sufficient number of subjects in the high RSA group. There were no significant effects involving the RSA factor.

The heart rate change for the 2.5-s period preceding and following the interrupting stimulus onset was analyzed with age, procedures, and intervals and with RSA category (including both preterm and full-term infants). Because the results from the age, procedures, and interval variables were reported in the previous section, only the interactions involving the RSA variable were tested. The only significant effect was an interaction of RSA × Intervals, Wilks $\Lambda = .6722$, $F(6,116) = 4.24$, $p < .01$. Figure 2 illustrates the heart rate changes from this period for the RSA groups separately for the four procedures. For the heart rate deceleration procedure and the 3-s and 7-s procedures, the heart rate change was the smallest in the lowest RSA group, at the next level in the middle group (low full-term RSA), and the largest in the highest RSA group ($ps < .05$). This result was particularly interesting for the 7-s procedure, because the heart rate response was nearly over for the lowest RSA group but was sustained throughout the period (for 9.5 s) for the other two groups.

Stability of Baseline Variables and Attention Responses

The stability of the baseline variables, the heart rate responses during fixation, and the time to distraction by the secondary stimulus were examined by looking at the correlations between responses between successive testing ages (14 and 20 weeks, and 20 and 26 weeks). Table 4 presents the first-order correlations between testing ages for these variables for the preterm infants alone and for the pre- and full-term infants combined. Table 4 also presents the between-age correlations of a combined variable consisting of the average Z score of the three baseline variables or across the four procedures at a testing age.

Significant correlations across the recording ages occurred for all the baseline variables as well as the combined variable, the sole exception being mean heart rate at 14 and 20 weeks. The preterm infants alone showed larger correlations across testing ages than did the full-term infants alone (i.e., Richards, 1989). For example, the preterm infants alone had correlations of .48 and .67 for the across-age respiratory sinus arrhythmia, as compared with .29 and .40 for the full-term infants (Richards, 1989, Table 1). Combining the preterm and full-term infants resulted in correlations similar to those of the preterm infants alone (Table 4).

There were several significant correlations for the heart rate change and the distraction time across the testing ages. The heart rate change during the 2.5-s period following the interrupting stimulus had moderate and significant correlations across the testing ages for the heart rate deceleration and the 3-s interrupted stimulus procedures (i.e., four of six possible correlations were

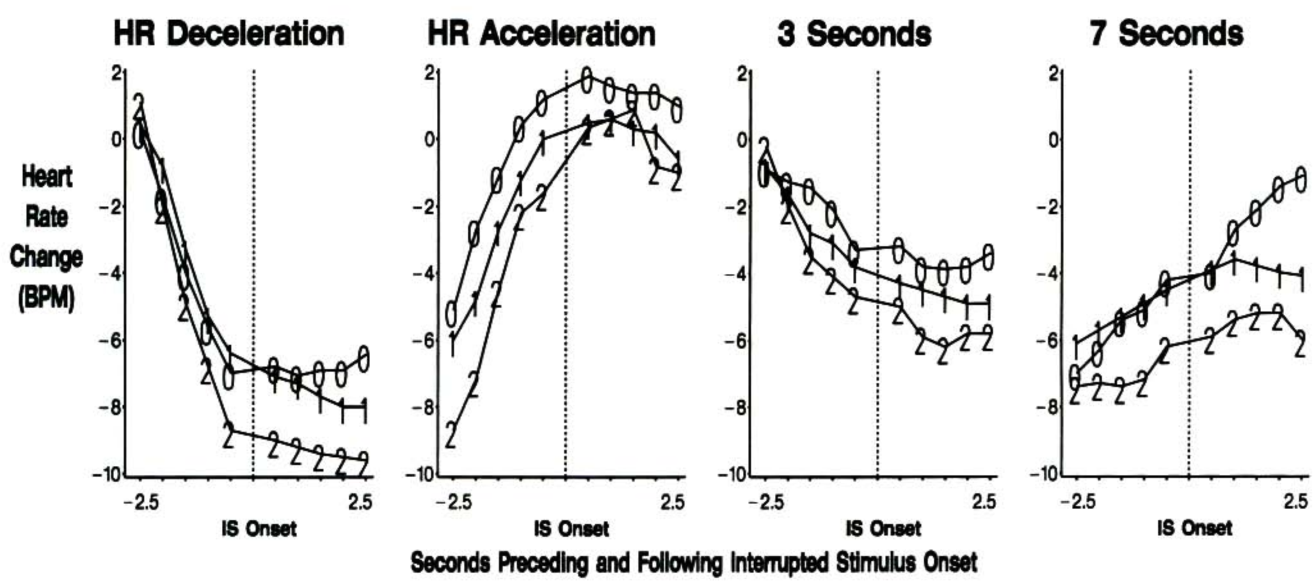

Figure 2. Mean heart rate change preceding and following the interrupting stimulus onset for the four interrupted stimulus procedures for the three categories of baseline respiratory sinus arrhythmia. 0 = RSA lower than that of all full-term infants; 1 = RSA lower than median value of full-term infants; 2 = RSA greater than median value of full-term infants.

Table 4. *Correlations Between Successive Testing Ages for Baseline and Experimental Variables*

	Preterm		Preterm and full term	
	14, 20 weeks	20, 26 weeks	14, 20 weeks	20, 26 weeks
Baseline				
Mean heart rate	−.007	.543**	.250*	.518**
SD heart rate	.605**	.353*	.638**	.275*
Respiratory sinus arrhythmia	.480**	.673**	.522**	.635**
Combined variables	.453**	.495**	.499**	.546**
Heart rate change during 2.5 s following interrupting stimulus				
Heart rate deceleration	.175	.558**	.363*	.347**
Heart rate acceleration	.220	−.060	.248*	.107
3 s	.477**	.388*	.180	.414**
7 s	.306	.085	.285*	.068
Combined procedures	.283	.131	.189	.409**
Time to distraction by interrupting stimulus				
Heart rate deceleration	.253	.068	.046	.162
Heart rate acceleration	−.112	.011	.009	−.043
3 s	.126	.117	.129	.022
7 s	.491**	.339*	.395**	.258*
Combined procedures	.440*	.338*	.421**	.306*

$^{*}p < .05$. $^{**}p < .01$.

significant for preterm alone, preterm and full term combined, and full term alone) (Table 4; Richards, 1989, Table 1). Thus, the heart rate response in these two procedures, which is hypothesized to be near the beginning of the sustained attention phase, was similar across the three testing ages for all subjects. Significant correlations across testing ages for the time to distraction by the interrupting stimulus occurred only for the 7-s procedure and for the variable combined across procedures.

Discussion

Heart Rate Responses

Heart rate variability (standard deviation and respiratory sinus arrhythmia) recorded during the baseline was lower in preterm infants than in the full-term infants. The heart rate response during stimulus orienting was attenuated in the RDS infants compared with the other preterm infants. The heart rate response near the interrupted stimulus (primarily heart rate deceleration procedure, representing sustained attention) became increasingly larger with age for the no respiratory complications and ventilation assistance preterm groups but increasingly smaller with age for the RDS infants. The form of the full-term infants' responses was very similar to those of the no respiratory complications and ventilation assistance infants and differed from that of the RDS group. The magnitude of the sustained attention response over the three testing ages increased for all infants except the RDS infants.

The smaller heart rate response during stimulus orienting in the RDS group, compared with the other preterm infants and the full-term infants, is consistent with some research on infants of this type but not with all previous research. Some studies with preterm infants tested before 40 weeks conceptional age have found that high-risk infants have smaller heart rate responses to acoustic stimuli than do low-risk infants or show accelerative heart rate responses, whereas low-risk infants have decelerative responses (Berkson et al., 1974; Schulman, 1970a, 1970b).

At least two studies tested preterm infants at ages similar to those in the present study. Fox and Lewis (1983) presented 3-month-old full-term, low-risk preterm, and RDS preterm infants with an acoustic stimulus for 10 s. They reported that the heart rate response for each group was the same. However, the RDS infants' heart rate responses failed to habituate with repeated presentations, unlike the responses of the other two groups. The comparison between the Fox and Lewis study and the current study is constrained by the form and duration of the heart rate responses in the two studies. Fox and Lewis found a cardiac deceleration over about seven to nine beats, with a return to prestimulus levels by 13–14 beats. That result would correspond in the present study only to the first few seconds of stimulus presentation, whereas differences in the heart rate response were found after 3 s (Figures 1 and 2). A study by O'Connor (1980) tested preterm infants at about 4 months of age (17 weeks). The heart rate changes reported in that study are more similar in magnitude, form, and duration to those in the present study. Preterm and full-term infants in that study did not differ on the heart rate response to a 12-s acoustic stimulus. However, the preterm infants in that study were not distinguished by risk status. Thus, those results are more similar to those found in the current study with low-risk infants. The results from the current study showing a diminished heart rate response in stimulus orienting for the RDS infants are unique.

Heart Rate Responses and Respiratory Sinus Arrhythmia

The relation between baseline respiratory sinus arrhythmia and heart rate responses in attention replicate findings from several previous studies. The heart rate response in the period immediately following the interrupting stimulus, when sustained attention is hypothesized to occur, was different in infants among the three RSA categories. Infants with the very lowest RSA had the least sustained heart rate response, infants with low RSA relative to the median of full-term infants had an intermediate sustained response, and infants with high RSA relative to full-term infants had the largest and longest sustained response. This finding is identical to that of several previous studies (e.g., Casey & Richards, 1988; Richards, 1987). As was found in those studies, neither the initial heart rate orienting to visual stimulus presentation nor the heart rate response at attention termination, the phase following sustained attention, was related to RSA magnitude. The current study extends the relation between RSA and heart rate response during sustained attention to infants with very low RSA. Those infants did not sustain the heart rate response during the period when sustained attention was presumed to occur. The relation between individual differences in RSA and attention found in healthy full-term infants continues to hold when RSA is at pathological or risk levels, as in the RDS infants (Richards, 1988; Richards & Casey, 1992).

The age changes in baseline RSA paralleled the heart rate responses of the preterm risk groups during sustained attention. The full-term, no respiratory complications, and ventilation assistance infants showed increases in RSA from 14 to 26 weeks, whereas the RDS infants showed a decrease in RSA over this age range. There was an increase in the heart rate response in the heart rate deceleration procedure for the no respiration complications, ventilation assistance, and full-term groups, whereas the RDS infants had a decrease in the heart rate response in this procedure.

This parallel between the increasing RSA levels and the increasing heart rate responses and between decreasing RSA levels and decreasing heart rate responses compares favorably with developmental functions found within the full-term infant group (Richards, 1989). Of particular interest are a group of full-term infants whose RSA increased over the age range from 14 to 26 weeks and a group whose RSA decreased over that same range. There was a corresponding increase in the heart rate response in the former group and a decreasing response in the latter. Intraindividual development in these groups in baseline RSA paralleled changes in heart rate during sustained attention. Similarly, in the present study the full-term (total group from Richards, 1989), no respiratory complications preterm, and ventilation assistance preterm infants had RSA increases paralleled by increases in heart rate responses. The RDS infants had RSA decreases and decreases in the heart rate response. Group RSA development functions are paralleled by group attention developmental function. Thus, the intraindividual developmental functions relating RSA development to sustained attention development are similar to the group functions.

The difference between the physiological measures in the preterm infants and the full-term infants suggests a developmental lag for low-risk infants, but a deficit for high-risk infants. All three preterm groups had lower RSA than the full-term group and smaller heart rate responses during attention. However, the two low-risk preterm infant groups showed developmental changes in these variables in the same manner as did full-term infants in this and other studies (e.g., Harper, Hoppenbrouwers, Sterman, McGinty, & Hodgman, 1976; Harper et al., 1978; Richards, 1987, 1989). These groups thus lag behind the full-term infants, even though matched for conceptional age, but show identical developmental patterns. On the other hand, the RDS preterm group failed to show the developmental changes in these variables, remained below the full-term infants, and began to lag behind the other preterm groups. This group, therefore, had a continuing deficit in the cardiorespiratory system controlling RSA and the central nervous system centers involved in sustained attention. This developmental lag for the low-risk preterm infants is similar to that reported by Ruff for focused attention responses to toys (Ruff, 1986; Ruff et al., 1984). In those studies, high- and low-risk infants showed less focused attention than did full-term infants at 6 months of age, but the low-risk infants caught up with the full-term infants by 9 months of age, whereas the high-risk preterm infants had a continuing deficit in focused attention. Some of these deficits in attention may then be associated with poor cognitive outcome in later childhood (e.g., recognition memory; Rose, Feldman, & Wallace, 1988; Rose & Wallace, 1985).

An apparent dissociation exists between risk status defined by perinatal events, concurrent RSA magnitude, and heart rate responses during attention. The RDS infants showed a smaller heart rate response during stimulus orienting. However, very low RSA infants responded differently during sustained attention than did high RSA infants but did not show distinctive responses during stimulus orienting. Thus, the irregular responses of the RDS infants in the stimulus orienting phase imply that characteristics of the RDS infants other than their low RSA levels affected stimulus orienting. The relation between RSA and sustained attention, however, affects both the RDS and other infants. A clear effect of risk status was found in the very small heart rate change during the heart rate deceleration trials in the RDS group and the lack of age changes in those measures. However, RSA level was linearly related to the heart rate response during sustained attention irrespective of risk group assignment (Figure 2). This finding is particularly noteworthy because the no respiratory complications preterm group had equal numbers of very low RSA and low RSA infants, and the three preterm risk categories were confounded with RSA groups (Table 3). The low RSA infants, from either the low-risk or RDS groups, failed to sustain the heart rate response during sustained attention. The diagnosis of RDS or identification at birth as high/low risk in itself is not critical for understanding the responses in sustained attention. The continuing deficit in RSA corresponds to the attenuated heart rate responses occurring in sustained attention.

Stability of Baseline and Responses

One of the goals of the study was to examine the stability of baseline heart rate measures across 14–26 weeks and the stability of the responses during attention. Moderate stability occurs in respiratory sinus arrhythmia measured from 3 to 6 months (e.g., correlations range from .3 to .49; Izard et al., 1991; Richards, 1989), and from 5 to 14 months (Fox, 1989). The moderate stability may be due in part to limited distributions found in full-term infants. In the current study, the preterm infants had much lower levels of RSA and heart rate variability than did the full-term infants but had higher correlations between measures across testing ages. The expansion of the range of RSA may have disattenuated the moderate correlations found in full-term infants. Preterm infants, who show very low RSA levels relative to full-term infants, may have a damaged cardiorespiratory control system, the effects of which last at least through the first 6 months of conceptional age.

The implications of the stability of attention in this study are not as clear as those found with the baseline recordings. Heart rate changes and behavioral responses during sustained attention showed only low or moderate correlations from 14 to 20 weeks and from 20 to 26 weeks of age. The size of these correlations was slightly higher in the preterm infants than in the full-term infants for some measures, but the reverse was true for others (cf. Table 4 with Richards, 1989, Table 3). However, a systematic pattern of interpretable differences was not evident. The level of these correlations across this age range was similar to that reported previously (e.g., Colombo, Mitchell, O'Brien, & Horowitz, 1987). Thus, the parallel changes found in the risk groups for RSA and heart rate responses during attention do not necessarily lead to across-age correlations that would strongly support consequential individual differences in the attention responses.

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