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The Development of Sustained Visual Attention in Infants from 14 to 26 Weeks of Age

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ABSTRACT

The development of sustained visual attention was examined in infants cross-sectionally at 14, 20, and 26 weeks of age. Heart rate, heart rate variability, and respiratory sinus arrhythmia were measured in a 5-min baseline period. Two methods for measuring visual attention were used. The "infant control" method consisted of checkerboard presentations which were terminated when the infant looked away from them. The "interrupted stimulus" method consisted of a blinking panel in addition to the checkerboard patterns in order to attempt to actively terminate the fixation. The visual and cardiac responses during the interrupted stimulus method were more highly correlated with baseline respiratory sinus arrhythmia than were the responses during the infant control trials. The long latency heart rate responses during the interrupted stimulus trials showed a developmental change toward more mature response patterns from 14 to 26 weeks of age. It may be concluded that: 1) sustained attention, measured with the interrupted stimulus method, increases from 14 to 26 weeks of age; and 2) baseline respiratory sinus arrhythmia is correlated with sustained attention responses and their development.

DESCRIPTORS: **Infancy, Heart rate, Respiratory sinus arrhythmia, Visual attention, Sustained attention.**

Heart rate variability, particularly variability due to respiratory sinus arrhythmia, is known to index the attentional responsivity of infants. Several studies with newborn infants (e.g., Porges, 1974; Porges, Arnold, & Forbes, 1973; Porges, Stamps, & Walter, 1974; Vranekovic, Hock, Isaac, & Cordero, 1974; Williams, Schacter, & Tobin, 1967) have shown that heart rate responses to psychological stimulation occur more often and with greater strength in infants with greater variability in heart rate. More recently, Richards (1985) found that the strength of respiratory sinus arrhythmia recorded during a baseline period was associated with the strength of the heart rate decelerative response during visual attention in 14 and 20 week old infants. It was even the case in that study that more mature visual fixation durations were correlated with the extent of sinus arrhythmia measured during the baseline condition.

An explanation for the relationship between heart rate variability and attentional responses has been offered by Porges (Porges, 1976, 1980). It is argued that attention processes are facilitated by cholinergic activity in the central nervous system which inhibits ongoing behavior and allows the focusing of attention. This should be particularly true for "sustained" attention, which is subject-controlled, endogenous attention, occurring after the first 5 to 6 seconds of "reactive" attention, and which involves the inhibition of motor behavior. Individual differences in attention therefore could be indexed if one had an adequate measure of the "cholinergic nervous system." It is the case that heart rate variability occurring at the same frequency as respiration, respiratory sinus arrhythmia, is largely produced by vagal efferent influences on the heart (Anrep, Pascual, & Rossler, 1935; Katona & Jih, 1975; Porges, McCabe, & Yongue, 1982). Since the vagal control of the heart is mediated by acetylcholine, the extent of sinus arrhythmia is an index of the strength of the cholinergic system, and therefore should index individual differences in attention responses. Presumably, this should not be limited to heart rate responses, but be related to other components of attention, such as fixation.

One of the weaknesses of the studies testing this theory with infants is the lack of a good measure of sustained visual attention. Previous studies of infant visual attention have used either fixed duration trials or the infant control procedure to de-

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termine trial length. Studies using fixed duration stimuli are inadequate because of the high percentage of subject attrition due to boredom after the information in the stimulus has been processed, and because of the need to document heart rate changes when the infant is actually looking at the stimulus (Lewis & Spaulding, 1967). The "infant control procedure" (Cohen, 1972; Horowitz, Paden, Bhana, & Self, 1972) consists of the presentation of stimuli for as long as the infant is fixating, and the stimuli are terminated at the end of fixation. The measure of attention is the duration of fixation. However, one cannot be sure that the infant is actively attending during the length of fixation. Rather, the infant may be fixating without any active cognitive processing of the information.

A useful technique for measuring infant sustained visual attention may be the "interrupted stimulus" method. This method is based on the concept of a "limited information processing channel" (Broadbent, 1958). People are limited in the amount of external information to which attention can be given, and if cognitive resources are dedicated to a search task, other tasks cannot be performed. An operational definition of the resource demands of a primary (central) task is performance on a secondary task, or the amount of time or intensity of stimulation that is needed to distract the subject from the primary task. This method often has been used with adults, and has been profitably used in psychophysiological studies with adults (e.g., Dawson, Schell, Beers, & Kelly, 1982; Wickens, Kramer, Vanasse, & Donchin, 1983). This procedure should be useful for infant subjects because it brings the termination of fixation under active experimental control rather than allowing the infant to fixate on the stimulus without being actively engaged in cognitive processing of the stimulus. The duration of fixation during the interrupted stimulus trials should therefore measure the extent of attention given to the central stimulus, since fixation would be coincident with active allocation of processing resources.

The present study compared the interrupted stimulus method with the infant control method for measuring sustained visual attention in infants from 14 to 26 weeks of age. Heart rate, heart rate variance, and two indices of respiratory sinus arrhythmia were recorded during a baseline period. Respiratory sinus arrhythmia may be quantified with spectral analysis techniques. Therefore, the extent of sinus arrhythmia was defined as the power of the heart rate spectrum at the modal frequency of respiration (Harper et al., 1978; Porges et al., 1982). The weighted coherence was defined as the proportion of variance in the heart rate spectrum predictable from the coherence between heart rate and respiration (Porges et al., 1980). Infants were presented with primary visual stimuli which were interrupted by a secondary visual stimulus on one-half of the trials. Checkerboard patterns of differing complexity were used as the primary stimuli in order to obtain varying amounts of attention. Heart rate responses were measured during fixation, and attention to the central task was defined as the amount of time that the infant fixated on the stimulus. The amount of cognitive resources dedicated to the task by the subject is "subject-controlled," endogenous attention, and therefore is like "sustained attention" as defined by Porges (1976, 1980). Therefore, baseline heart rate variability (e.g., respiratory sinus arrhythmia) should be more highly correlated with fixation and heart rate responses occurring during the interrupted stimulus trials than during the infant control trials, since the former procedure is a better measure of sustained visual attention.

Methods

Subjects

Infants for this study were recruited from birth notices in a Columbia, South Carolina, newspaper. The infants were full-term, and the parents reported no prior perinatal medical complications. A cross-sectional design was used to sample infants at 14, 20, and 26 weeks of age. The mean testing age of the infants was 99.8 days (SD = 2.68), 141.0 days (SD = 2.52), and 182.2 days (SD = 1.80), respectively. Eighteen subjects at each age were used. In order to optimize cardiac and visual responding, the testing was done only if the subjects maintained in an alert, awake state during the entire procedure (eyes open, no fussing or crying, responding to the protocol). Nine additional infants did not complete the testing because they did not maintain this state.

Apparatus

The infant was held in its parent's lap approximately 51 cm from the center of a black and white 49 cm (19 in.) television monitor. There was a single LED located on either side of the television screen 23 cm from the center, and one located on the bottom center. These LEDs blinked at a rate of 3.33 Hz when turned on. A video camera lens was located above the television monitor, and a television monitor was located in an adjacent room and was used by an observer to record infant fixations. The area around the television monitor and panels, and on the sides of the parent, was covered with a neutrally colored cloth panel in order to block extraneous visual information.

The stimuli for the central task (primary stimuli) were computer-generated checkerboard patterns. They were presented on the television monitor in a 30 cm (1 ft) square area and were either 2.54, 1.27, or 0.635 cm (1.0, 0.5, or 0.25 in.) in size. The patterns were either presented continuously or changed from black to white at 6.25 Hz. The sizes of the checks were chosen

from hypothetical developmental changes in pattern preferences (Karmel & Maisel, 1975), and corresponded to the approximate maximum preferences for contour density at 8, 14, and 20 weeks of age. The interrupting stimuli (secondary stimuli) consisted of two 17 × 11 cm panels and were located 42 cm to either side of the center of the screen. These panels had 20 LEDs which blinked on and off at 16 Hz in a sequential pattern resembling a circle, with the circle being completed approximately each second.

Procedure

The physiological measures were first recorded during a 5-min baseline 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 his or her lap facing the screen. Prior to the experimental trials the secondary stimuli were presented for 3 trials in order to acquaint the infant with their location. Each trial began with a 5-s period with no stimuli. Following this, one of the single LEDs on the side of the television monitor was activated, and when the infant looked in the direction of the blinking LED the panel on the same side was turned on. The infant control procedure for stimulus presentations (Cohen, 1972; Horowitz et al., 1972) was used such that as long as the infant was looking at the stimulus panel it remained on, and the trial was terminated when the infant looked away from the panel.

The experimental trials consisted of the presentation of the primary visual stimuli, the checkerboard patterns, interrupted on one-half of the trials with the secondary stimuli. The blinking light at the bottom of the screen was turned on following a 5-s period with no stimuli, and a checkerboard pattern was presented when the infant looked in the direction of the blinking light. The checkerboard stimulus remained on as long as the infant was looking at it, and was turned off when the infant looked away. The "infant control" trials consisted of the presentation of the primary stimulus by itself. The "interrupted stimulus" trials consisted of the presentation of the checkerboard stimulus simultaneously with the blinking light on the side of the monitor, and when the infant looked away from the checkerboard pattern toward the "interrupting" stimulus the panel was activated. The panel remained on for 10 s, or until the infant stopped looking at it. Heart rate was recorded only during the prestimulus and the checkerboard presentations. Each infant was presented with the three levels of checkerboard complexity, presented both blinking and continuously, for both the "infant control" and the "interrupted stimulus" trials, resulting in 12 trials. An additional control trial with a blank screen was presented with the infant control and interrupted stimulus methods. This resulted in a total of 14 experimental trials, the order of which was chosen randomly for each child.

Measurement and Quantification of Physiological Variables

The EKG was recorded by placing Ag-AgCl electrodes on the infant's chest with disposable electrode collars. Beat-to-beat intervals were computed online with an Apple IIe microcomputer by identifying the R-R intervals in the EKG with 1 ms resolution. The beat-to-beat heart period intervals were converted to heart 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. Heart rate was calculated on a 0.5-s by 0.5-s basis for heart rate mean and variance and on a 0.1-s by 0.1-s basis for the spectral analysis measures. Respiration was measured with a cloth belt placed around the infant's chest, and a mercury strain gage was used to detect thoracic circumference changes due to respiration. The respiration signal was digitized online at 50 Hz by an Apple IIe computer. Respiration frequency was quantified by computing on a breath-to-breath basis the respiration cycle period (20 ms resolution), converting that to rate (breaths per min), and assigning values to 0.5-s intervals in the same manner as was done with heart rate. Heart rate was recorded in the baseline period as well as during the attention trials. Respiration frequency was quantified only for the baseline periods, in order to determine the modal respiration frequency for the quantification of respiratory sinus arrhythmia. Heart rate rather than period was chosen to coordinate the computation of mean heart rate with the computation of mean fixation duration in the attention trials (Graham, 1978; Richards, 1980).

Heart rate variability measures were quantified from the 5-min baseline recording. The mean and variance of the 0.5-s intervals of the baseline were computed for heart rate. The variance of the heart rate intervals was transformed by the natural logarithm function for the data analysis. Two measures were computed for the baseline period based on spectral analysis procedures. These measures were computed from heart rate values assigned to 0.1-s intervals, and the respiration signal sampled at 0.1-s intervals. The first 512 0.1-s intervals of each of the 5 min was used, giving a frequency resolution of 0.01953 Hz. The spectral analysis measures were extracted separately from the data for each baseline minute, and the extracted measures were averaged over these 5 baseline periods. The extent of sinus arrhythmia was defined as the power of the heart rate spectrum at the modal respiration frequency for that baseline period (Harper et al., 1978; cf. Porges et al., 1982). This power measure was transformed by the natural logarithm function for the data analysis. The weighted coherence was defined as the proportion of variance of the heart rate spectrum that was predictable from the respiration spectrum (Porges et al., 1980), and was summed over 0.1953 Hz (11.71 breaths per min) centered at the modal respiration frequency for the period.

Experimental Design for Statistical Analysis

The factorial design for the analysis of the results included testing age as a between-subjects factor, and within-subjects factors for procedure (infant control and interrupted stimulus trials), blinking checks (blinking and non-blinking checks), and checkerboard complexity level (low, medium, and high). The levels of the dependent variables on the two control trials were subtracted from the levels on the experimental trials. There was no "intervals" factor for the 0.5-s by 0.5-s heart rate data, since the trials were necessarily of differing lengths. The relationship between baseline heart rate variability and attention responses was assessed by correlations between the baseline measures and the attentional responses. Unless noted, the significance of the ANOVA test was unchanged by applying the *maximum* conservative adjustment of the degrees of freedom according to the Greenhouse and Geisser method (Greenhouse & Geisser, 1959; see Richards, 1980). However, if the maximum conservative adjustment resulted in a nonsignificant ANOVA test, the proportional *epsilon* adjustment was made and the statistical significance of the proportionally adjusted test was used.

Results

Baseline Measures

The baseline measures of heart rate and heart rate variability were analyzed with a multivariate ANOVA with testing age as a factor to assess the presence of preexisting differences in this between-subjects factor. There was a significant main effect of testing age on the multiple dependent variables, *Wilks Lambda* = .6639, $F(8/96) = 2.73$, $p<.01$. Table 1 presents the univariate means of the baseline variables for each age along with the significance of the individual one-way ANOVAs for those variables. The decrease in heart rate over this age approached statistical reliability, and the extent of sinus arrhythmia and the weighted coherence increased over this age period. The correlations between the baseline variables are also presented in Table 1.

Table 1

Mean baseline heart rate and heart rate variability levels for all three ages tested, and correlations between baseline heart rate variability measures

	Means (SDs in Parentheses)			
Ages	HR	HR Variance	Extent of Sinus Arrhythmia*	Weighted Coherence*
14 weeks	155.0 (8.84)	3.97 (0.47)	1.82 (0.746)	.443 (.079)
20 weeks	149.4 (9.14)	3.85 (0.51)	2.16 (0.656)	.479 (.083)
26 weeks	147.3 (11.43)	3.91 (0.60)	3.28 (0.587)	.524 (.059)

	Correlations		
Measures	HR	HR Variance	Extent of Sinus Arrhythmia
HR Variance	−.103		
Extent of Sinus Arrhythmia	−.137	.486**	
Weighted Coherence	−.329**	.118	.022

*significantly different across ages, $p<.05$.
**correlation significant at $p<.01$.

Infant Control and Interrupted Stimulus Presentations

Fixation Duration. The duration of the fixation during the presentations of the primary stimuli was analyzed with an Age(3) × Procedure(2) × Blinking Checks(2) × Complexity(3) ANOVA. There was a significant main effect of testing age, $F(2/51) = 17.54$, $p<.001$. Infants at 14 weeks of age looked at the stimuli for the longest duration (12.5 s), at 20 weeks for an intermediate duration (8.3 s), and at 26 weeks for the shortest duration (7.0 s). There was also a main effect of the type of procedure, $F(1/51) = 6.02$, $p<.01$. The duration of looking in the trials using the infant control method was longer than in those using the interrupted stimulus method (9.90 s compared with 8.01 s). There were statistically significant main effects for the blinking/non-blinking factor ($F(1/51) = 8.86$, $p<.01$), and for the stimulus complexity level ($F(2/102) = 5.50$, $p<.01$). Infants looked longer at the blinking (mean = 9.9 s) than at the continuously presented checks (mean = 8.9 s). The means on the low, medium, and high complexity checkerboards were 9.08 s, 10.7 s, and 8.6 s, respectively. However, the differences resulting from these two factors are not of direct interest to the experimental questions because they do not interact with procedure or age. The procedure × complexity and the age × procedure × blinking × complexity effects were statistically significant before adjustment by the Greenhouse and Geisser method, but were not significant when the *epsilon* adjustment was made.

Heart Rate Change. Heart rate was analyzed as the difference between the mean level of heart rate during the entire fixation period and the mean heart rate level during the 5 seconds preceding fixation, with an Age(3) × Procedure(2) × Blinking(2) × Stimulus Complexity(3) ANOVA. The only significant effect on the heart rate response was the age × procedure interaction, $F(2/51) = 4.19$, $p<.05$. A simple main effects analysis was used to test the difference between the three age groups separately for the infant control and the interrupted stimulus trials. The mean heart rate responses of the three age groups on the infant control trials were not significantly different (means = −2.02, −2.24, and −1.69 bpm for the 14, 20, and 26 week olds, respectively). On the other hand, the difference between the means for the interrupted stimulus trials was statistically significant ($p<.05$). There were approximately equal differences among the three groups, with the 14-week-olds showing the least deceleration (−2.11 bpm), the 26-week-olds showing an intermediate value (−2.97 bpm), and the 20-week-olds showing the largest mean response (−3.87).

Short and Long Latency Heart Rate Changes. Figure 1 illustrates the pattern of 0.5-s by 0.5-s heart rate change that occurred during fixation for the three age groups during the two procedures. The pattern of heart rate change for the 14-week-old infants was identical in the two presentation methods (Figure 1A). There was a deceleration of heart rate in the first 5 seconds of the infant control and interrupted stimulus trials for the 20 (Figure 1B) and the 26 week olds (Figure 1C). Then, heart rate during the infant control trials quickly began to return to prestimulus levels for both ages, whereas in the interrupted stimulus trials the lower heart rate level was sustained for these older infants (Figures 1B and 1C).

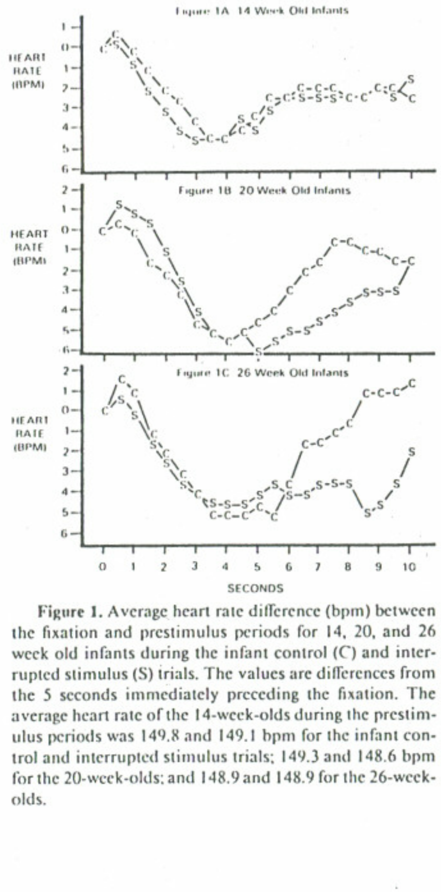

Figure 1. Average heart rate difference (bpm) between the fixation and prestimulus periods for 14, 20, and 26 week old infants during the infant control (C) and interrupted stimulus (S) trials. The values are differences from the 5 seconds immediately preceding the fixation. The average heart rate of the 14-week-olds during the prestimulus periods was 149.8 and 149.1 bpm for the infant control and interrupted stimulus trials; 149.3 and 148.6 bpm for the 20-week-olds; and 148.9 and 148.9 for the 26-week-olds.

The 0.5-s by 0.5-s changes illustrated in Figure 1 were not statistically analyzed because of the differing lengths of the individual trials due to the use of infant-determined presentation lengths. However, developmental trends in heart rate responses after the first 5 seconds of fixation were examined statistically by calculating heart rate change from the prestimulus level for the first 5 seconds of fixation (short latency) and for heart rate change in the second 5 seconds (long latency). Since many trials were less than 5 seconds in length, the short and long latency heart rate changes were taken from any trial over 5 seconds in length and the mean of those trials was computed for each subject separately for the two procedures. All subjects had at least one trial that met this criterion from the two procedures, and the overall percentages of these trials were 62%, 45%, and 41% for the 14, 20, and 26 week old groups, respectively. The differing percentages were consistent with the differences in visual fixation duration reported earlier. Although some of the long latency means were computed on trials of less than 10-s duration, these trials were included based on the assumption that the attention processes occurring during the second 5 seconds were different from those occurring in the first 5 seconds regardless of total fixation duration.

The heart rate change for the short and long latency phases was analyzed with an Age(3) × Procedure(2) × Phase(2; short and long latency) ANOVA. The procedure × phase interaction significantly affected the heart rate variable, $F(1/51) = 8.17$, $p<.01$. Heart rate increased from the short to the long latency periods for the infant control trials (−3.10 bpm to −1.65 bpm, respectively) but decreased from the short to the long latency periods for the interrupted stimulus trials (−2.92 bpm to −3.49 bpm). However, a more important significant interaction that affected heart rate was the age × procedure × phase effect, $F(2/51) = 5.25$, $p<.01$). *Post hoc* comparisons revealed the absence of an age × phase effect for the infant control trials, and a significant age × phase effect for the interrupted stimulus trials ($p<.01$). Figure 2 presents the short and long latency heart rate changes for the different ages and procedures. Heart rate increased from the short to long latency periods for all three ages in the infant control trials (Figure 2A), whereas heart rate level in the interrupted stimulus trials increased for the 14-week-olds, and decreased for the 20 and 26 week olds (Figure 2B).

Correlation of Responses with Baseline Heart Rate Variability

Fixation Duration. The correlations between the baseline measures and visual fixation duration are

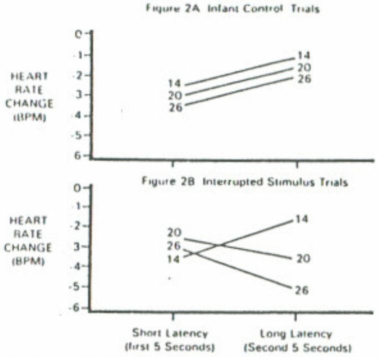

Figure 2. Average heart rate difference (bpm) between the prestimulus period and the first 5 seconds of fixation (short latency) and the second 5 seconds of fixation (long latency) for 14, 20, and 26 week old infants during the infant control and interrupted stimulus trials.

Table 2

Correlations between baseline heart rate variability and visual fixation and heart rate responses during visual attention for all subjects in the different experimental techniques

Experimental Techniques	Correlations			
	HR	HR Variance	Extent of Sinus Arrhythmia	Weighted Coherence
Visual Fixation Duration				
Infant Control	−.002	.104	−.213	.013
Interrupted Stimulus	.103	.044	−.218*	−.238*
Both Procedures	.053	.086	−.245*	−.120
Heart Rate Responses				
Infant Control	−.100	.169	−.074	.153
Interrupted Stimulus	−.221	−.104	−.293*	.022
Both Procedures	−.170	.038	−.246*	.115

*$p<.05$, **$p<.01$.

presented in Table 2 separately for each procedure, and combined. The extent of sinus arrhythmia was significantly correlated with fixation duration for the interrupted stimulus but not the infant control trials. The negative correlation indicates that greater amounts of respiratory sinus arrhythmia were associated with shorter visual fixation durations. The weighted coherence measure was significantly correlated with visual fixation duration only for the interrupted stimulus trials. As with the extent of sinus arrhythmia, shorter visual fixation duration was associated with larger values of the weighted coherence.

Table 3

Correlations between baseline heart rate variability and short and long latency heart rate responses for all subjects in the different experimental techniques

Experimental Techniques	Correlations			
	HR	HR Variance	Extent of Sinus Arrhythmia	Weighted Coherence
Short Latency Responses				
Infant Control	−.090	−.193	−.105	.033
Interrupted Stimulus	−.047	−.084	−.034	−.065
Both Procedures	−.091	−.183	−.092	−.022
Long Latency Responses				
Infant Control	−.100	−.288**	−.124	−.102
Interrupted Stimulus	−.008	−.199	−.425**	−.283*
Both Procedures	−.060	−.291**	−.351**	−.245*

*$p<.05$, **$p<.01$.

Heart Rate Change. The correlations between heart rate change over the entire fixation period and the baseline measures of heart rate variability are presented in Table 2 separately for each procedure, and combined. The extent of sinus arrhythmia was significantly correlated with the heart rate change, though only for the interrupted stimulus trials. The direction of the correlation indicates that the larger the extent of sinus arrhythmia was during the baseline recording, the greater the heart rate deceleration response was during fixation on the interrupted stimulus trials.

Short and Long Latency Heart Rate Changes. Table 3 presents the correlations for the short and long latency periods separately for the infant control and interrupted stimulus procedures. Heart rate variance, extent of sinus arrhythmia, and weighted coherence in the baseline were significantly correlated with the long latency but not the short latency responses (Table 3). For all of these, the strength of the physiological variable in the baseline was positively associated with the strength of the sustained deceleration in the long latency period. Additionally, the weighted coherence and the extent of sinus arrhythmia were significantly related to long latency responses for the interrupted stimulus trials but not for the infant control trials (Table 3).

Discussion

This study confirms the findings of Richards (1985), and earlier findings with newborn infants, that resting level of heart rate variability is correlated with the attentional responsivity of the infant. As was the case with Richards (1985), it was specifically the spectral estimate of the extent of respiratory sinus arrhythmia that was most highly correlated with heart rate responses and visual fixation responses (cf. Porges et al., 1982). Since the amplitude of respiratory sinus arrhythmia is an index of cardiac vagal tone (Katona & Jih, 1975; Porges et al., 1982), these results imply that the level of vagal tone may be used to index sustained attention behavior in the young infant. The stronger the vagal tone, the larger the heart rate deceleration during attention, and the more mature the visual fixation responses (cf. Richards, 1985).

These results again confirm the usefulness of the indexing of infant attentional responsivity with baseline heart rate variability (Porges, 1976, 1980). Porges argued that the cholinergic activity indexed by respiratory sinus arrhythmia facilitated attention by inhibiting non-essential motor behavior. This type of behavior inhibition was posited to be most characteristic of the "sustained" component of attention, occurring approximately 6 seconds following the onset of stimulation (Porges, 1976). This hypothesis was directly supported in the present study. It was the long latency responses (sustained attention) rather than the short latency responses (reactive attention) that were most highly correlated with the extent of sinus arrhythmia and the weighted coherence recorded in the baseline period. If it can be assumed that the interrupted stimulus trials are a reasonable measure of the extent of active cognitive processing, then the significant relationships that were found between the baseline heart rate variability measures and the attentional responses during the interrupted stimulus trials suggest that "sustained attention capacity" is closely linked with the ability of infants to allocate information processing resources to a visual attention task.

There were no age differences in the absolute magnitude of the decelerative response, but prior research has not necessarily established that there should have been. Early research (summarized by Graham et al., 1970) found an increase in decelerative strength from 6 weeks of age (3 to 4 bpm) to 12 weeks (7 bpm) to 16 weeks (17 bpm) in response to a 75dB, 1000 Hz tone. However, Berg (1974) found approximately the same level of deceleration in 6 and 16 week old infants (about 10 bpm) on the average response of the first two trials of a habituation sequence, attributing his finding to a more rigorous control of behavioral state during testing. Those studies that have used visual stimuli (e.g., Lewis, Kagan, Campbell, & Kalafat, 1966; Lewis & Spaulding, 1967) have typically been limited to a single age and reported only the results for mean of the several extreme beats and did not report second-by-second results. Thus, there were no precedents for expecting what should happen developmentally to the heart rate response to visual stimuli over this age range. The average maximum deceleration in the present study was about 6 to 7 bpm for all three age groups, comparable to the Berg results. The average maximum heart rate response for the three familiarization trials with the secondary stimulus (not reported in results) was approximately 11 bpm for all three ages, almost identical to the levels reported by Berg (1974). The present results suggest that the findings of Richards (1985) of an accelerative response for 14-week-olds to similar stimuli, and the weak decelerative response for the 20-week-old infants in that study, resulted from an accelerative response accompanying the head movement toward the stimulus due to the methodology used in that study.

There was an important developmental trend found in the sustained attention responses during fixation. The youngest infants showed nearly identical patterns of heart rate responses for the infant control and the interrupted stimulus trials. The 20 and 26 week olds showed a pattern of heart rate on the 0.5-s by 0.5-s means similar to the 14-week-olds only for the infant control trials. On the other hand, the initial heart rate decelerations during the interrupted stimulus trials were increasingly sustained for the 20 and 26 week old infants. Identifying these long latency responses as "sustained attention" implies that there is an increase in sustained attention over this age period. Since the interrupted stimulus procedure is a measure of the active allocation of processing resources, this could be thought of as an increase in the ability to direct attention to an interesting stimulus. Other investigators (e.g., Rose, 1983; Zelazo & Kearsley, 1982) have shown that over the first year of life infants increase in their ability to process information quickly. This finding is consistent with the shorter fixation durations of the older infants in this study and in Richards (1985). Thus, not only are infants able to process information more quickly with increasing age, they show better attention processes (e.g., more sustained heart rate responses) as they get older. The present results imply that these increases in processing efficiency and quicker processing times may be due to developmental differences in the quality of attention directed toward visual stimuli.

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