Development and Stability in Visual Sustained Attention in 14, 20, and 26 Week Old Infants

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ABSTRACT

Infants were studied at 14, 20, and 26 weeks of age in a longitudinal design. They were presented with varying and complex patterns on a TV screen. Two-thirds of the presentations were accompanied by a stimulus in the periphery delayed in time from the onset of fixation on the central stimulus. As in previous research, the infants were not as easily distracted by the interrupting stimulus when the presentation occurred at the point of maximal heart rate deceleration as when the presentation occurred at the end of the heart rate response. Infants with large amounts of respiratory sinus arrhythmia (i.e., heart rate variability) in a baseline recording were less distractible during the deceleration-defined trials than were infants with low amounts of respiratory sinus arrhythmia. Intra-individual patterns of development in respiratory sinus arrhythmia over the testing ages were closely paralleled by patterns of heart rate responding during sustained attention. Individual differences in baseline levels of heart rate and respiratory sinus arrhythmia were more stable than individual differences in sustained attention. The stability of attention responses over age may be mediated by the stability of the physiological system (e.g., heart rate, respiratory sinus arrhythmia, etc.), and by the within-age relation of attention to heart rate variability.

DESCRIPTORS: Attention, Heart rate, Infants, Respiratory sinus arrhythmia.

The stability over age of infant attention has recently become an important research issue. One reason for this concern is that measures of attention, habituation, and memory are correlated with cognitive or intellectual outcome in later childhood (e.g., Bornstein & Sigman, 1986; Cohen & Parmelee, 1983; Fagan & McGrath, 1981; Fagan & Singer, 1983; Lewis & Brooks-Gunn, 1981; Rose & Wallace, 1985). However, the predictive ability of a measure is limited by its reliability. One measure of reliability is the test-retest correlation. Test-retest correlations of infant attention measures over both short (e.g., days) and longer (1 to 3 months) periods of time are low to moderate in level (e.g., Bornstein & Benasich, 1986; Colombo, Mitchell, O'Brien, & Horowitz, 1987; Rose, Feldman, & Wallace, 1988), or nonsignificant (Colombo et al., 1987; Maitre, Lamarre, & Pomerleau, 1987; McCall, 1979). These low test-retest correlations indicate that infant at-

tention measures have low reliability. The observed correlations between infant attention and childhood outcome may be attenuated by the low level of reliability (Bornstein & Sigman, 1986).

A second reason for the interest in the stability of attention in infancy is based on a theoretical model of infant sustained attention (Porges, 1976, 1980). Multiple components of infant attention may be distinguished, two of which are reactive and sustained attention. Reactive attention is an involuntary, phasic response to the onset of a stimulus, and lasts for 5 or 6 seconds. Sustained attention is a voluntary, active response to stimulation, which begins after reactive attention and facilitates information and stimulus processing. Porges argues that the cholinergic nervous system activity is important in the inhibition of peripheral body activity, which is a critical component of voluntary, sustained attention. An indirect index of cholinergic activity is respiratory sinus arrhythmia, which is the variability in heart rate that occurs at the same frequency as breathing, and occurs due to vagal parasympathetic activity, mediated via cholinergic mechanisms. Individual differences in sustained attention should therefore be related to individual differences in level of respiratory sinus arrhythmia, because the latter is indexing a functional charac-

teristic of the central nervous system that is involved in the control of sustained attention.

There are substantial individual differences in infant sustained attention within a testing age (Richards, 1988). If these are stable characteristics of the infant's attentional response, then there should be significant test-retest correlations between sustained attention measures at two ages. A recent report by Ruff, Lawson, and Parinello (1987) found evidence for the stability of sustained attention. The latency to touch small, graspable objects, and the amount of time spent examining those objects, were measured in infants at 12 and 24 months of age. There was a correlation between object examination time at 12 and 24 months, but not between touch latency over these months of age. Developmental changes in object examination time and touch latency differ. Latency to touch an object decreases with age, whereas object examination time does not (Ruff, 1986). Object examination time may be similar to sustained attention, because it involves the active encoding of stimulus information, whereas touch latency may be more similar to a reactive phase of attention, such as stimulus orienting. The results of these two studies imply that the developmental changes and individual differences affecting attention differ for the sustained and reactive phases of attention.

However, stability in the measures of sustained attention may depend on the level of intra-individual stability in respiratory sinus arrhythmia (RSA). Over the first 12 months of life, heart rate variability and RSA levels increase (Harper, Hoppenbrouwers, Sterman, McGinty, & Hodgman, 1976; Harper et al., 1978; Katona, Frasz, & Egbert, 1980; Richards, 1985b, 1987; Watanabe, Iwase, & Hara, 1973). These changes may be due to the increasing influence of the parasympathetic nervous system on heart rate variability (Egbert & Katona, 1980). There is a close association between level of respiratory sinus arrhythmia and infant attention responses over this age range. RSA level has been shown to be positively correlated with heart rate deceleration in a variety of visual attention tasks, including habituation (Richards, 1985a), sustained attention (Richards, 1985b, 1987), visual preference (Casey & Richards, 1988), and recognition memory (Linnemeyer & Porges, 1986). Respiratory sinus arrhythmia was related in those studies to behavioral measures of attention, such as visual fixation duration (e.g., Richards, 1987) and recognition memory performance (Linnemeyer & Porges, 1986). Attentional responses are coupled to the processes controlling RSA level, so developmental changes in respiratory sinus arrhythmia should affect the pattern of development of the attentional system. It is not known whether the developmental changes in infant RSA level are accompanied by intra-individual stability, i.e., reliable test-retest correlations between respiratory sinus arrhythmia at different ages, or whether there are irregular patterns of RSA change within individuals. Irregular patterns of development of respiratory sinus arrhythmia could result in irregular patterns of attention development, and attenuate test-retest correlations of attention measures. On the other hand, stable RSA development patterns might be the basis for the observed test-retest correlations of attention measures.

The current study was an examination of both development and stability in infant visual sustained attention. The methods for measuring visual attention replicated those of Richards (1987) and Casey and Richards (1988). Visual attention and respiratory sinus arrhythmia were measured in infants who were tested in a longitudinal design at 14, 20, and 26 weeks of age. These ages were the same as in previous studies (e.g., Richards, 1985b, 1987) that showed RSA-attention relations, and the development of both respiratory sinus arrhythmia and sustained attention. These ages and the longitudinal design allow for the examination of the parallels between intra-individual developmental change patterns in respiratory sinus arrhythmia and in the attention responses.

Methods

Subjects

Infants for this study were recruited from birth notices in a Columbia, South Carolina, newspaper. The infants were full-term, defined as having birthweight of greater than 2500 g and gestational age of 38 weeks or greater determined by the mother's report of her last menstrual cycle. The parents reported no pre- or perinatal medical complications. Twenty-eight infants completed testing in a longitudinal design at ages 14, 20, and 26 weeks. An additional 8 infants did not complete the longitudinal protocol and are not included in this analysis. The mean testing ages of the infants were 99.2 days (SD=2.23), 141.7 days (SD=3.69), and 183.5 days (SD=5.48), respectively. 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). Subjects that did not maintain this state during testing were tested again in the same week. Four subjects were tested a second time at 14, two at 20, and three at 26 weeks of age.

Apparatus

The testing apparatus and stimuli were described in detail in Richards (1987). The infant was held in its parent's lap approximately 51 cm from the center of a black and white 49 cm TV monitor (19 in. TV). The primary stimuli were three patterns shown on the

TV monitor. The stimuli were a recording of a Sesame Street TV program, a computer-generated checkerboard pattern, and a series of computer-generated, concentric squares. All stimuli were presented in a 30 cm square area on the monitor, subtending approximately 32° visual angle. The stimuli for the interrupted stimulus trials consisted of two 17×11 cm panels with 20 LEDs which 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 EKG were recorded for a 5-min period during which the infant was seated on the parent's lap away from the testing apparatus. The parent was instructed not to bounce or move the infant, but the infant's movements were not restrained. The parent was then seated in the chair with the child on the lap facing the TV screen. The LED panels were presented for 4 trials in order 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.

The experimental trials consisted of 4 infant control trials and 8 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, and the presentation of one of the secondary stimuli at a predetermined delay from the onset of visual fixation on the primary stimulus. The time of the secondary stimulus onset was based on one of the following criteria: (a) three-second—presented when 3 s had elapsed, (b) seven-second—presented when 7 s had elapsed, (c) heart rate deceleration—presented when a significant deceleration of heart rate had occurred, and (d) heart rate acceleration—presented when heart rate began to return to the prestimulus level following a heart rate deceleration. A heart rate deceleration was defined as five successive beats with heart period longer than the median period of the five heartbeats preceding the presentation of the primary stimulus. The return of heart rate to the prestimulus level on the heart rate acceleration trials was defined as five successive beats with heart period shorter than the median period of the five prestimulus heartbeats, and must have followed a deceleration. Two 6-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 being randomly chosen within each 6-trial block.

Measurement and Quantification of Physiological Variables

The EKG was recorded with Ag-AgCl electrodes on the infant's chest. Beat-to-beat intervals were computed online with an IBM PC microcomputer by identifying the R-wave of the EKG and measuring R-R intervals with 1-ms resolution. The evaluation of heart rate during heart rate deceleration and heart rate acceleration trials was made with machine language programs on the IBM PC which made the evaluation within 1.1 ms of the criterion beat. For quantitative analyses, the beat-to-beat heart period intervals were converted to rate (bpm) by assigning values to equal time 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 by 0.1-s heart rate intervals) and 500 ms for the experimental trials (0.5-s by 0.5-s heart rate intervals) (see Graham, 1978). Rate was chosen as the cardiac function to coordinate the heart response with fixation patterns 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 online at 50 Hz by an IBM PC 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, in order to determine the modal respiration frequency for the quantification of respiratory sinus arrhythmia.

A measure of respiratory sinus arrhythmia was computed from the baseline recording of the EKG with spectral analysis methods. The 0.1-s by 0.1-s heart rate series was first detrended with a bandpass filter, designed to pass the frequencies associated with infant respiration (Porges, 1986). The extent of respiratory sinus arrhythmia was defined as the power of heart rate summed over a frequency range of 0.1953 Hz (11.71 breaths per minute) and centered at the modal respiration frequency for that baseline period (Richards, 1985b, 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 extent of respiratory sinus arrhythmia is the natural logarithm of the root-mean-squared variation of heart rate at the respiration frequency ranges. The heart rate power spectrum was 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 minutes were used, giving a frequency resolution of 0.01953 Hz. The value was extracted separately from the data for each period, and was averaged over these five baseline minutes.

Results

Baseline Heart Rate and Respiratory Sinus Arrhythmia

The mean of the baseline 0.1-s by 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

Table 1

Mean baseline levels and correlations between the heart rate measures across the testing ages

| Baseline Measures | Mean Baseline Levels (SDs in Parentheses) | | | Correlations Between Testing Ages | | |
	14 Weeks	20 Weeks	26 Weeks	14 & 20 Weeks	20 & 26 Weeks	14 & 26 Weeks
Heart Rate	153.8 (11.4)	146.0 (12.6)	142.4 (11.5)	.50**	.46**	.47**
Heart Rate SD	13.8 (2.5)	12.9 (1.4)	10.3 (3.1)	.08	.05	.03
Extent of RSA	1.24 (0.87)	1.52 (0.66)	1.96 (0.98)	.29	.40**	.32*

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

ANOVA with age as the factor. All three variables showed a significant age effect (p's$<.01$). Across the three testing ages there was a decline in mean heart rate level and the standard deviation of heart rate values, and an increase in extent of respiratory sinus arrhythmia (Table 1). Table 1 also contains the correlations of the variables across the three testing ages. Mean heart rate level and extent of respiratory sinus arrhythmia were significantly positively correlated across all three ages, whereas the standard deviation of heart rate was not.

Heart Rate and Behavioral Responses during Attention

The heart rate responses during attention, and time to distraction by the secondary stimulus, were analyzed as in Richards (1987). The results found with the experimental procedures (heart rate deceleration, heart rate acceleration, three-second, seven-second) of that study were substantially replicated, and will be only briefly summarized here. The infants were less easily distracted by the secondary stimulus when it was presented contingent on heart rate deceleration than when it was presented contingent on heart rate returning to the prestimulus level. The level of respiratory sinus arrhythmia distinguished between large and small heart rate responses, and distraction times, but only for the heart rate deceleration trials. The level of heart rate on the heart rate deceleration trials in the period immediately following the secondary stimulus, which reflects the cognitive processing intensity, increased from 14 to 26 weeks of age.

Intra-Individual Development of Baseline and Attentional Measures

The longitudinal design of the study allowed the examination of intra-individual patterns of change in the baseline physiological measures, and the relation of those patterns to the attentional responses. Subjects were divided into four groups based on changes in respiratory sinus arrhythmia (RSA) occurring across the three testing ages: Group 1: continuously decreasing RSA (N=3); Group 2: contin-

uously increasing RSA (N=8); Group 3: increase in RSA from 14 to 20 weeks, followed by a decrease from 20 to 26 weeks (N=8); and Group 4: decrease in RSA level from 14 to 20 weeks, followed by an increase from 20 to 26 weeks (N=9). Mean RSA level over this age range increased (Table 1), and this is reflected in the finding that Groups 3 and 4, which show decreases and increases in respiratory sinus arrhythmia over the testing ages, increase overall in RSA level.

Heart rate responses during attention were examined for the four groups. The difference between the mean heart rate level in the 2.5-s prestimulus period and the 2.5-s period following the secondary stimulus onset was visually examined. The pattern of age changes for the heart rate response from the heart rate deceleration trials was nearly identical to the pattern of the four baseline RSA groups. The pattern of age changes in the heart rate response from the three-second and seven-second trials was similar to the baseline pattern for some of the four groups, but not others. The heart rate response and baseline patterns on the heart rate acceleration trials were dissimilar in the four groups. Figure 1 presents the developmental changes in heart rate responses during the heart rate deceleration trials for the four groups. Group 1, which decreased in RSA level over the testing ages, also had a continuous decrease in the attention-related heart rate change. Group 2 showed a continuous increase in RSA level and a continuous increase in the size of the heart rate change. The two groups having mixed changes in baseline respiratory sinus arrhythmia (Groups 3 and 4) had parallel changes in the heart rate response at the same ages. Thus, for the heart rate deceleration procedure, the patterns of intra-individual changes in respiratory sinus arrhythmia were matched by age changes in attention-linked heart rate responses.

An analysis of intra-individual change similar to that done with baseline respiratory sinus arrhythmia was done for baseline heart rate. The subjects were divided into four groups based on the pattern of baseline heart rate change over the three testing

Groups Defined by Baseline RSA Age Change
1: Across age RSA decrease
2: Across age RSA increase
3: RSA increase then decrease
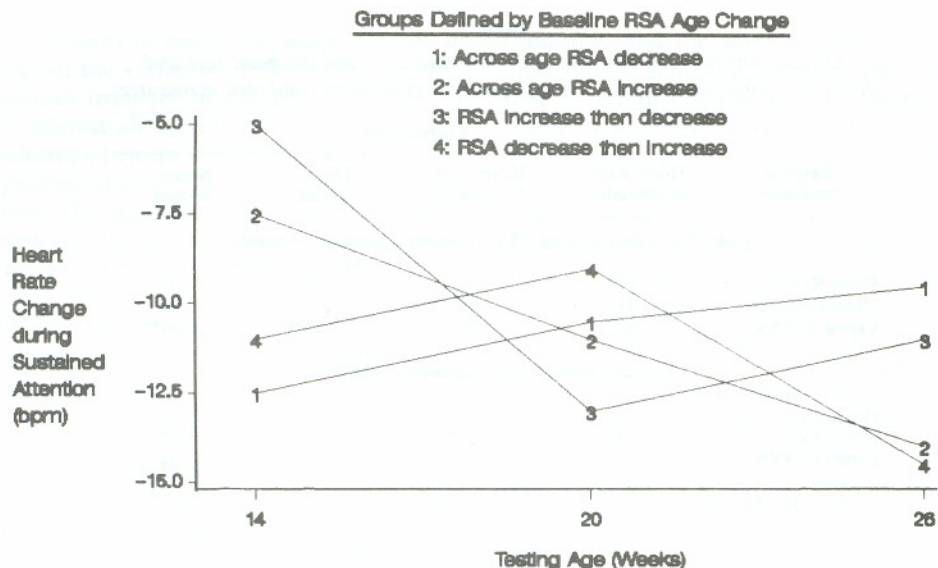4: RSA decrease then increase

Figure 1. Mean heart rate change following the secondary stimulus onset, classified by baseline change patterns in respiratory sinus arrhythmia (RSA) (see text).

Groups Defined by Baseline HR Age Change
1: Across age HR decrease
2: Across age HR increase
3: HR increase then decrease
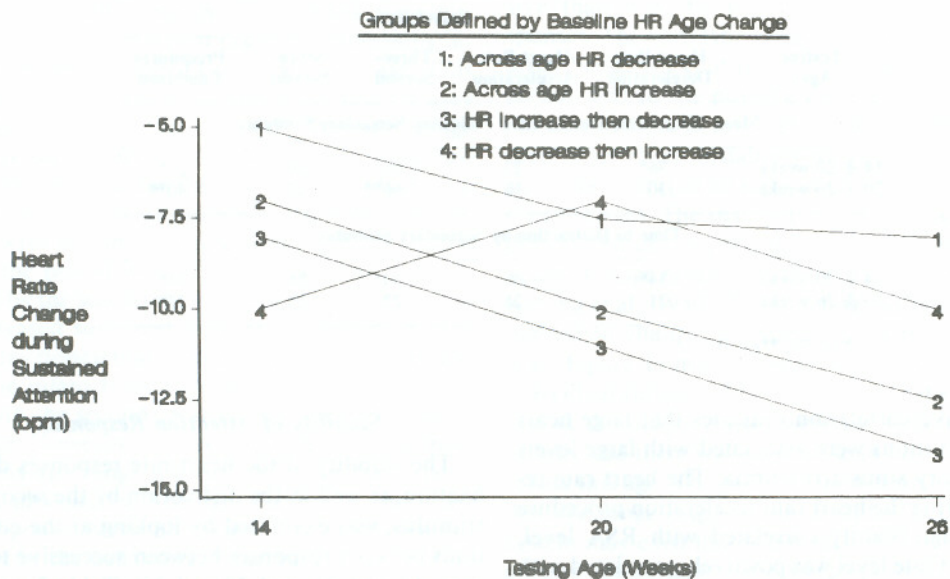4: HR decrease then increase

Figure 2. Mean heart rate change following the secondary stimulus onset, classified by baseline change patterns in heart rate (HR) (see text).

ages. Heart rate responses during attention were examined for these groups. The pattern of age changes in the heart rate response and the pattern of the four baseline heart rate groups were dissimilar for all four experimental procedures. For example, Figure 2 presents the heart rate responses during the heart rate deceleration procedure for the four baseline heart rate groups. The pattern of developmental change in baseline heart rate was not paralleled by the attention-linked heart rate responses, unlike the results found with baseline respiratory sinus arrhythmia.

The relation between the relative levels at the three ages of baseline physiological measures and attentional responses was examined with correlation coefficients. Correlations were computed between the baseline physiological variables, and the heart rate change and distraction time for the four interrupted stimulus procedures combined across the three testing ages. Table 2 contains the resulting correlations. The heart rate response during the heart rate deceleration, three-second, and seven-second procedures was negatively correlated with the level of respiratory sinus arrhythmia (RSA).

Table 2

Correlations between baseline heart rate measures and the heart rate and distraction time responses for the experimental procedures combined across ages

Baseline Measures	Correlations			
	Heart Rate Deceleration	Heart Rate Acceleration	Three-Second	Seven-Second
Mean Heart Rate During 2.5 s Following Secondary Stimulus				
Heart Rate	.19	.07	.16	.09
Heart Rate SD	−.03	.02	−.11	.01
Extent of RSA	−.68**	.06	−.52**	−.40**
Time to Distraction by Secondary Stimulus				
Heart Rate	.23*	.07	.21*	.17
Heart Rate SD	.44**	.21*	.27*	.12
Extent of RSA	.08	−.10	−.14	−.04

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

Table 3

Correlations between successive testing ages for the heart rate and distraction time responses across the experimental procedures

Testing Ages	Correlations				
	Heart Rate Deceleration	Heart Rate Acceleration	Three-Second	Seven-Second	Procedures Combined
Mean Heart Rate During 2.5 s Following Secondary Stimulus					
14 & 20 weeks	.36*	.23	−.01	.26	.27*
20 & 26 weeks	.30	.18	.66**	.02	.40**
Time to Distraction by Secondary Stimulus					
14 & 20 weeks	.34*	−.08	.34*	.26	.36*
20 & 26 weeks	.21	−.28	.22	.23	.32*

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

The negative correlation indicates that large heart rate decelerations were associated with large levels of respiratory sinus arrhythmia. The heart rate response during the heart rate acceleration procedure was not significantly correlated with RSA level. Mean heart rate level was positively correlated with distraction time on two of the procedures, and the standard deviation of heart rate values was correlated with distraction time on three of the procedures. The pattern of these results corroborates the relations found between baseline RSA change patterns and heart rate responses during attention (e.g., Figures 1 and 2).[1]

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[1]The inclusion of multiple observations from the same subject violates the statistical assumption of independent observations for correlation coefficients and may limit the interpretation of the statistical significance of the correlations. However, this procedure should show the strength of the baseline-attention association given the age-related changes in both the baseline and attention measures.

Stability of Attention Responses

The stability of the heart rate responses during fixation, as well as the distraction by the secondary stimulus, was examined by looking at the correlations between responses between successive testing ages (14 and 20, and 20 and 26). Table 3 presents the first-order correlations between testing ages for the mean heart rate level in the 2.5 s following the secondary stimulus onset, and the time to distraction by the secondary stimulus. Table 3 also presents the between-age correlations of a combined variable which consists of the average Z-score of the four procedures at a testing age. Significant correlations across test ages occurred for the heart rate deceleration and three-second trials. The combined variable showed moderate and significant correlations across the two ages. The seven-second and the heart rate acceleration trials were not significantly correlated across the testing ages. The relationship of the stability of the attention responses to the

baseline measures of heart rate was examined by partialing out the variation of the within-age baseline measures from the across-age correlations in Table 3. Almost all correlations in Table 3 were nonsignificant when the covariation with the baseline physiological measures was partialed out of the correlation. The only statistically significant partial correlation was for the three-second procedure between the 20 and 26 week testing ages (Pearson $r = .42$, $p < .05$). The average absolute correlation size was .13. Thus, the variance shared at different ages by the attention variables also was shared by the heart rate variables.

Discussion

A consistent pattern of developmental changes in sustained attention has emerged from this and previous studies (Casey & Richards, 1988; Richards, 1985b, 1987). The most significant developmental change in heart rate occurred in the sustained phase of attention. The level of heart rate on the heart rate deceleration trials in the period immediately following the interrupted stimulus, which reflects the status of cognitive processing intensity, increased from 14 to 26 weeks of age. This finding replicates data from previous studies (Casey & Richards, 1988; Richards, 1987). This age change parallels the finding of an increasingly sustained heart rate response for the older age infants during the sustained period of attention (Richards, 1985b). Thus, with the increasing age levels used in this study, the period in which the infant was not distracted by the secondary stimulus was accompanied by increased sustained heart rate responding. Another developmental change was the time to distract the infant from looking at the primary stimulus with the secondary stimulus, which decreased with age. However, the decline in distraction times over this age range did not differ for the experimental procedures. The age changes in the heart rate responses were not exactly paralleled by age changes in the behavioral responses.

The results of the current study support only a low stability of individual differences in sustained attention. The correlations were moderately positive, with an inconsistent pattern of statistical significance. The combination of the individual trial measures resulted in correlations from about .3 to .4 between successive testing ages for both heart rate and distraction time. The level of these correlations was similar to that which has been reported in other studies (Colombo et al., 1987; Rose et al., 1988; Ruff et al., 1987). Certain measures of infant attention are more highly correlated across testing ages than are other measures (Colombo et al., 1987). Along this same line, in the present study the attention measures during the heart rate acceleration condition, and the seven-second condition, were uncorrelated across age, whereas the heart rate responses and distraction times on the heart rate deceleration and three-second conditions were significantly correlated. Although not entirely overlapping, the three-second and heart rate deceleration procedures may produce similar results because they are more closely associated in time than they are with the other two procedures. However, the heart rate deceleration condition is a better procedure for assessing sustained attention, because the behavioral attention response and relation to respiratory sinus arrhythmia is related more closely to level of the heart rate response than it is to time of the secondary stimulus (Richards, 1987). These results imply that sustained attention may be based on a reliable individual difference system whereas reactive attention and attention termination are not.

The stability of the baseline physiological variables over the three testing ages was more impressive than was the stability of the attention responses. The correlations between respiratory sinus arrhythmia (RSA) at the different ages were as expected, and in the positive direction. The level of the correlations is low (.29 to .40), implying that there is as much instability as stability in the relative placement of an individual's RSA level at the different ages. The instability in RSA level is likely due to the developmental changes in RSA level across this age range (e.g., Harper et al., 1976, 1978; Katona et al., 1980). The differing patterns of intra-individual change in respiratory sinus arrhythmia (e.g., Figure 1) may account for the lack of intra-individual stability. The correlations between heart rate at the different ages were the largest in magnitude, and there was a decrease in heart rate level across this age. The correlation of heart rate across this age range suggests that a stable physiological system may exist that is not exclusive to the mechanisms responsible for respiratory sinus arrhythmia, but may include distinct (though related) processes of the central nervous system. These results are consistent with the existence of stable individual differences in a physiological system across these ages in spite of the significant changes in heart rate level and heart rate variability.

The consistent relation between baseline heart rate variability and attention responses is strongly supported by this study. Respiratory sinus arrhythmia was related to the behavioral and physiological indices of attention on the trials in which attention was posited to be the most active (heart rate deceleration trials), and for sustained attention rather than reactive attention. Intra-individual develop-

ment in baseline respiratory sinus arrhythmia was paralleled by changes in heart rate during sustained attention. Not only was the pattern preserved, but the relative level of respiratory sinus arrhythmia (RSA) over the entire testing period was paralleled by the relative level of heart rate change during attention over the same testing period. Also, the test-retest correlations of the attention parameters (heart rate and behavioral) measured at the three testing ages lost their statistical significance when the variance shared with the baseline heart rate variables was removed. Fluctuations in the RSA system that are local to a testing age show up as fluctuations in the attention system. The low levels of

stability in the attention system may be a result of short-term fluctuations in respiratory sinus arrhythmia, or in the physiological systems involved in the control of heart rate, respiratory sinus arrhythmia, and respiration. An individual differences model relating heart rate variability and attention (e.g., Porges, 1976, 1980; Richards, 1988) should emphasize the stability of the underlying physiological system rather than the attentional parameters. Consistency between attention responses over age seems to be mediated by the stability of the physiological system (e.g., heart rate, respiratory sinus arrhythmia, etc.) and the within-age relation of attention to heart rate variability.

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