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Respiratory Sinus Arrhythmia Predicts Heart Rate and Visual Responses during Visual Attention in 14 and 20 Week Old Infants

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ABSTRACT

The prediction of cardiac attentional responses by respiratory sinus arrhythmia was tested in infants at 14 and at 20 weeks of age. Heart rate, heart rate variability, and respiratory sinus arrhythmia were measured in a 5-min baseline period. Respiration and heart rate responses were recorded during the habituation of infant visual attention. The level of respiratory sinus arrhythmia in the baseline was significantly correlated with the cardiac deceleration, especially in the 20-weekold infants. The relationship between cardiac and respiratory responses during attention was stronger in the 20-week-olds, paralleling the increase in respiratory sinus arrhythmia at this age. Visual fixation durations were also significantly correlated with measures of heart rate variability from the baseline. These results imply that cardiac variability not only predicts the level of cardiac attentional responsivity, but may be useful in the indexing of individual differences in the responsivity of more general attentional systems.

DESCRIPTORS: Heart rate, Respiratory sinus arrhythmia, Visual attention, Infants.

Respiratory sinus arrhythmia may be related to individual differences in heart rate responses during attention in 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 "mature" heart rate responses to psychological stimulation (e.g., heart rate deceleration) occur more often and with greater strength in infants with greater variability in heart rate. 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; Yongue et al., 1982). It is often assumed that phasic changes in heart rate during attention are of vagal origin (Coles, Pellegrini, & Wilson, 1982; Graham, 1973; Graham & Clifton, 1966; Lacey & Lacey, 1977; Porges, 1976; Obrist, Webb, Sutterer,

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Address requests for reprints to: John E. Richards, Department of Psychology, University of South Carolina, Columbia, SC 29208. & Howard, 1970). If it is true that the vagus is critically involved in heart rate attention responses, then it may be possible, by measuring the heart rate variability attributable to respiratory sinus arrhythmia, to measure individual differences in the capacity of the heart to respond with changes in rate during attention, by measuring the level of vagal tone. Respiratory sinus arrhythmia may also be an index of other attentional processes which are related to the cholinergic activity of the nervous system (Porges, 1976).

It is not necessarily the case that respiratory sinus arrhythmia in heart rate indexes attentional responsivity because it is measuring vagal tone. It also measures the extent to which respiration influences heart rate during resting. It therefore may measure the *potential* influence of respiration responses on heart rate during attention. Studies of physiological changes during attention with children and adults have shown a link between both tonic and phasic heart rate and respiration changes. Tasks involving increased attention demands often are accompanied by sustained decreases in respiration frequency and amplitude which are coincident with heart rate deceleration and heart rate variability decreases (Coles, 1972; Cheung & Porges, 1977; Porges & Humphrey, 1977; Porges & Raskin, 1969; Walter & Porges, 1976). Other studies have demonstrated

that the phase of respiration in which the stimulus is presented affects phasic heart rate changes over several seconds (Turpin & Sartory, 1980) or within individual cardiac cycles (Coles et al., 1982). It may be that respiratory sinus arrhythmia indexes the strength of the influence of respiration on heart rate during attention, and therefore may indirectly index the level of heart rate changes during attention.

The early period of infancy is a time during which these theories of the indexing of cardiac attentional responsivity with respiratory sinus arrhythmia can be tested because of naturally occurring developmental changes in the levels of cardiac variability and respiratory sinus arrhythmia. Overall variability of heart rate increases from one to six months of age in the human infant (Harper, Hoppenbrouwers, Sterman, McGinty, & Hodgman, 1974; Katona, Frasz, & Egbert, 1980; Watanabe, Iwase, & Hara, 1973). This increase is also true for variability in heart rate specifically attributable to respiratory sinus arrhythmia (Harper et al., 1978; Katona et al., 1980). During this same period, at least for continuous auditory stimuli, there is a trend from a predominance of cardiac accelerative responses during stimulation at birth to a decelerative response increasing in strength from 6 weeks to 4 months of age (Graham et al., 1970; see review by Berg & Berg, 1978). If it is the case that heart rate variability is indexing attentional responsivity of heart rate, then the changing sensitivity of the heart rate decelerative response during attention should be indexed by parallel developmental changes in respiratory sinus arrhythmia.

The present study was designed to assess the indexing of heart rate and visual attention changes with respiratory sinus arrhythmia, and the relationship of heart rate and respiration responses during attention. Therefore, heart rate, heart rate variability, and respiratory sinus arrhythmia were measured in a baseline period. Heart rate and respiration of 14 and 20 week old infants were measured during the habituation of visual attention to stimuli of differing complexity. The habituation paradigm was chosen because it systematically manipulates infant attention, and the stimuli of differing levels of complexity also result in different amounts of attention. The ages were chosen because over this range respiratory sinus arrhythmia and heart rate variability are increasing, and there is some change in the sensitivity of the cardiac decelerative response.

Methods

Subjects

Infants in this study were recruited from birth notices in a local newspaper. The infants were full-term, and the mothers reported no pre- or perinatal medical complications. A cross-sectional design was used to sample infants at 14 and at 20 weeks of age. The 14week-old group had a mean age of 99.7 days (SD = 2.73), and the 20-week-old group had a mean age of 141.3 days (SD = 2.85). Each infant was randomly assigned to one of three experimental conditions of stimulus complexity. Seven subjects of each sex were used at each age and in each of the stimulus complexity conditions, resulting in a total sample of 84 infants. In order to optimize cardiac responding, the 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). Sixteen additional infants did not complete the testing session because they did not maintain this state. The data from 6 subjects could not be used because of recording or technical difficulties. Subjects were tested at least 90 min following a feeding, and were not allowed the use of a pacifier during testing.

Apparatus

The apparatus follows that described by Cohen (1972). The infant was placed in an infant seat facing a 4 \times 4 ft vertical stimulus panel of grey material which was surrounded by two 4×4 ft panels to block extraneous visual information. Two 12×12 in. white screens were mounted on the vertical panel 2 in. to the right or left of the center of the panel. The centers of the screens were located at a distance of 20 in. from the infant's eyes. A 24 V bulb with a translucent cover 0.7 in. in diameter was located 5 in. below the bottom edge of either screen. When turned on, the lights blinked at a rate of 0.2 s on and 0.2 s off. A video camera was located behind the panel to record infant eye movements through a 1.5 in. hole centered between the two white screens. A television monitor was located in an adjacent area and was used by an observer to record infant fixations.

The habituation stimuli were black and white checkerboard patterns projected on the white screens by a carousel projector located above and behind the infant's head. There were three sizes of checks, corresponding to low (1 in., 12×12), medium (.5 in., 24×24), and high (.25 in., 48×48) stimulus complexity levels. These patterns were chosen from the analysis of hypothetical developmental changes in pattern preferences by Karmel and Maisel (1975). The chosen patterns corresponded to the approximate maximum preferences for contour density at 8, 14, and 20 weeks of age (Karmel & Maisel, 1975).

The response recovery stimulus was the same for all subjects. This stimulus was a color picture of a red ball with a small yellow stripe, and it was projected to the full 12-in. screen. The dishabituation stimulus was the same stimulus as was presented on the habituation trials.

Procedure

The physiological measures were first recorded during a 5-min baseline during which time the infant was on the mother's lap. The child was placed in the infant

seat following this baseline, and the habituation procedure was begun. The habituation procedure was adapted from the infant control procedure for visual habituation (Cohen, 1972; Horowitz, Paden, Bhana, & Self, 1972). Each trial began with either the right or left blinking light being randomly chosen and turned on. When the infant looked in the direction of the blinking light, the light was turned off and the checkerboard stimulus was presented on the side opposite the blinking light. The stimulus presentation was terminated when the infant looked away from it. Following a 2.5-s interval, a new trial was begun. A single observer judged the direction of infant fixation, and was blind to the side on which the blinking light and the slide were presented. The "latency" period for each trial was defined as beginning when the blinking light had been turned off and lasting until the infant looked at the checkerboard stimulus. The "fixation" period was defined as beginning with the start of fixation on the stimulus and ending when the infant looked away from the stimulus.

During the habituation trials, the checkerboard pattern appropriate to the stimulus complexity condition of the subject was presented randomly on either side of the vertical stimulus panel. The habituation trials were continued until the infant reached a habituation criterion of fixation time on 3 successive trials equal to or less than one-half of the average fixation time on the first 3 trials. The habituation trials were followed by 3 response recovery trials, in which the same procedure was used but the response recovery stimulus was presented instead of the checkerboard stimulus. The response recovery trials were followed by the dishabituation trials, during which the original checkerboard stimulus was re-presented for 3 trials.

Measurement and Quantification of Physiological Variables

The EKG was recorded by placing Ag-AgCl electrodes on the infant's chest, and was stored on FM magnetic tape. Beat-to-beat heart period intervals were computed offline by a PDP-11 laboratory computer with a 1-ms resolution. The beat-to-beat heart periods were converted to .5-s by .5-s heart rate (bpm) by assigning values to .5-s intervals based on the number of beats in the interval weighted by the proportion of time that the beat occupied the interval. 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 recorded on FM magnetic tape, and was sampled offline by a PDP-11 computer at 50 Hz. Respiration frequency was quantified by computing on a breath-to-breath basis the respiration cycle period (20-ms resolution), converting that to rate (breaths/min), and assigning values to .5-s intervals in the same manner as was done with heart rate. Respiration amplitude was defined as the amplitude of the excursion of the DC record from inspiration to inspiration peak, quantified as the percentage of the infant's maximum excursion, and was assigned

to .5-s intervals as were heart rate and respiration frequency. The marker channel on the polygraph was also digitized in order to synchronize the physiological recordings and experimental events.

Several measures of heart rate variability were quantified from the 5-min baseline recording. The mean and variance of the .5-s intervals of the baseline were computed for heart rate. Several measures were computed for the baseline based on spectral analysis procedures (Harper, Scalabassi, & Estrin, 1974; Harper et al., 1978; Womack, 1971). The first 51.2 s of each of the 5 min was used, which gave a frequency resolution of .01953 Hz, and the spectral analysis measures were averaged over these five 51.2-s periods. They included the summed power of heart rate for three low frequency bands, DC to .12 Hz, .12 to .24 Hz, and .24 to .36 Hz. The extent of sinus arrhythmia was defined as the power of the heart rate spectrum at the modal respiration frequency for that 51.2-s period (Harper et al., 1978; cf. Porges et al., 1982), and the coherence of sinus arrhythmia was defined as the coherence between the heart rate and respiration spectra at that same frequency (Harper et al., 1978). 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 .1953 Hz (11.71 breaths/min) centered at the modal respiration frequency for the 51.2-s period.

Experimental Design for Statistical Analysis

The factorial design for the results analysis used stimulus complexity as a between-subjects factor. Habituation phase was a repeated-measures factor, and was defined as the average of 3 trials for: 1) the first 3 trials, 2) the 3 trials on which the habituation criterion was met, 3) the response recovery trials, and 4) the dishabituation trials. A "trials" factor was not used since the habituation criterion was defined for the average of 3 trials, and the criterion was met on 3 successive trials. The .5-s by .5-s heart rate values were not analyzed with an "intervals" factor, since the trials were necessarily of differing lengths due to the use of the infant control procedure. The measures of baseline heart rate functioning were used as covariates for the duration of the fixation and latency periods, and for heart rate responses, to assess the relationship between attention responses and baseline heart rate variability. The differences between the mean of the .5-s by .5-s levels of heart rate, respiration frequency, and respiration amplitude in the latency and fixation periods of the trial (fixation minus latency) were used as covariates to assess the relationship between the physiological responses and visual fixation. Similiarly, respiration frequency and amplitude responses were used as covariates in the analyses of heart rate responses.

Testing age of the infant was a between-subjects factor for visual fixation duration and the latency duration. However, for heart rate, there was a significant negative relationship between the mean heart rate in the latency period and the difference score used in the analysis, F(1/1296) = 118.63, p < .001, indicating the

presence of a Law of Initial Values effect (Richards, 1980). There was also a significant age difference in this relationship, F(1/1296) = 30.72, p < .001. Therefore, the dependent variable for heart rate was adjusted by the latency mean separately for the two age groups, and the residual score was used in the analysis. Since the assumption of homogeneity of regression coefficients was not met in this data, testing age was not a factor for heart rate but analyses were done separately for each age group (Richards, 1980).

Results

Baseline Measures

The baseline measures of heart rate and heart rate variability were analyzed with multivariate ANOVAs with testing age and stimulus complexity as factors to assess the presence of preexisting differences in these between-subjects effects. The only significant effect on the multivariate variables was testing age, *Wilks Lambda* = .65252, F(12/67) = 3.34, p = .001. Table 1 presents the univariate means for the baseline variables, along with the significance values of the individual *t*-tests. Heart rate decreased over this age period, whereas the measures of heart rate variability, including respiratory sinus arrhythmia, showed larger variability in the 20 than in the 14 week old infants.

Visual Fixation Duration

The duration of the fixation on the stimulus was analyzed with ANOVA. There was a significant effect of age on fixation, F(1/78) = 27.25, p<.001. The 14-week-old infants had longer fixation durations (mean = 12.2 s) than the 20-week-olds (mean = 9.12 s). There was also a significant effect of habituation phase on fixation duration, F(3/234) =250.07, p<.001, and an interaction of age and phase, F(3/234) = 7.90, p<.001. Individual *a priori* comparison tests revealed significantly longer fixation on the first 3 trials than on the 3 criterion trials (p<.001), as would be expected from the definition

Table 1

Mean levels of heart rate and heart rate variability in the baseline for 14 and 20 week old infants and the probability of a significant difference

	Mean			
Baseline Measures	14 Weeks	20 Weeks	p Values	
Heart Rate	153.05	145.54	.001	
Heart Rate Variance	9.16	9.19	.955	
DC to .12 Hz Power	42.10	42.48	.001	
.12 to .24 Hz Power	39.58	39.89	.010	
.24 to .36 Hz Power	33.00	33.36	.005	
Extent of Sinus Arrhythmia	3.58	5.97	.015	
Arrhythmia	.419	.460	.053	
Weighted Coherence	.383	.404	.199	

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Durations of the latency and fixation periods for the 14 and 20 week old infants in the phases of habituation

Durations (s)				
Lat	ency	Fixation		
14 Weeks	20 Weeks	14 Weeks	20 Weeks	
8.8	6.7	19.6	13.5	
6.3	7.3	5.8	4.6	
6.7	5.5	17.8	14.1	
6.0	7.7	9.8	6.3	
	Late 14 Weeks 8.8 6.3 6.7 6.0	Duration Latency 14 20 Weeks Weeks 8.8 6.7 6.3 7.3 6.7 5.5 6.0 7.7	Durations (s) Latency Fixa 14 20 14 Weeks Weeks Weeks 8.8 6.7 19.6 6.3 7.3 5.8 6.7 5.5 17.8 6.0 7.7 9.8	

of the criterion trials (see Table 2). There was also a significant recovery of fixation to the response recovery stimulus and a dishabituation of fixation to the original stimulus (p's<.001, Table 2). The age by phase interaction was a reflection of the largest age differences being found on the visual fixation of the first 3 trials (p<.001), with a smaller but significant difference between the age groups on the response recovery and dishabituation trials (p's<.001), and the smallest difference on the criterion trials (p = .003, see Table 2). There were no reliable effects on visual fixation involving stimulus complexity.

The measures of heart rate variability from the baseline were significantly related to visual fixation durations in the covariance analysis, F(8/70) = 2.54, p = .017. Table 3 presents the correlations between

Table 3

Correlations between visual fixation duration and baseline heart rate variability measures, and physiological responses for the phases of habituation with attention

	Correlations				
Measures	First Three Trials	Response Recovery Trials	Dishabituation Trials		
28 29 (MA24) (1627)	Baseline Mea	sures			
Heart Rate	.169*	.070	.158		
Heart Rate Variance	039	049	001		
DC to .12 Hz Power	129	112	174*		
.12 to .24 Hz Power	121	041	082		
.24 to .36 Hz Power	256**	175*	082		
Extent of Sinus					
Arrhythmia	317**	208*	350**		
Coherence of Sinus					
Arrhythmia	216*	114	066		
Weighted Coherence	168	076	007		
Pł	ysiological Re	esponses	Stand Sta		
Heart Rate	.124	087	.015		
Respiration Frequency	061	062	.152		
Respiration					
Amplitude	089	132	068		

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

the baseline variables and the fixation durations on the first 3 trials, the response recovery trials, and the dishabituation trials. There was a consistent pattern of negative correlations between the measures of respiratory sinus arrhythmia and visual fixation duration, particularly for the extent of sinus arrhythmia. The physiological responses were also significantly related to visual fixation duration, F(27/196) = 2.58, p < .001. None of the individual correlations of these physiological response variables with fixation duration were significant (Table 3). However, of the three responses, the respiration amplitude change from the latency to the fixation period showed consistent negative correlations with fixation duration.

Latency Period Duration

The duration of the latency periods was analyzed with ANOVA. The only significant effect on this variable was an age by phase interaction, F(3/234)= 3.20, p = .024. For the individual phases, the age difference on latency duration only approached statistical significance for the first 3 trials (p = .089) and the dishabituation trials (p = .097), and the age difference was not significant on the other phases (see Table 2). The baseline variables and the physiological responses were not significantly related to the duration of the latency period in the covariance analyses.

Heart Rate

Heart rate was analyzed as the difference between the mean of the .5-s by .5-s heart rate levels in the latency and the fixation period of each trial (fixation minus latency), adjusted for the mean latency level. The constant term in the ANOVA model was statistically different from zero for the 14week-old infants, F(1/39) = 22.65, p < .001, as well as for the 20-week-old infants, F(1/39) = 5.74, p = .021. This indicates that there was a significant change from the latency to the fixation period for the heart rate of both ages. Figure 1 plots the .5-s by .5-s changes in heart rate for the two ages for the first 3 trials and the response recovery trials. The 14-week-old heart rate change was primarily accelerative, whereas the 20-week-old heart rate response was decelerative. The difference between the mean responses of the two ages represented in Figure 1 was significant, but the pattern of changes in Figure 1 is merely illustrative since an "intervals" factor was not statistically analyzed. Neither stimulus complexity nor habituation phase reliably affected the heart rate response for the 14-week-olds. There was a significant phase effect for the 20-weekold heart rate response, F(3/117) = 3.43, p = .025. Individual comparison tests showed a significant



Figure 1. Average heart rate differences (bpm) between the fixation and latency periods for 14 (open circles) and 20 (closed circles) week old infants on the first 3 trials and the response recovery trials. The values are differences from the average level for 2.5 s prior to the fixation. The 14-week-olds had means during the latency periods of 146.1 and 150.3 for the first 3 trials and the response recovery trials, respectively, and the 20-week-olds had latency period means of 143.0 and 147.5. The solid black lines near the ordinate are the average fixation durations on those trials.

difference between the heart rate response in the first 3 trials and the criterion trials (p = .013), the response recovery and the criterion trials (p = .029), and between the dishabituation and the criterion trials (p = .009).

The measures of cardiac rate and variability from the baseline were significantly related to heart rate responses during visual attention for the 20-weekolds, F(8/31) = 3.30, p = .008, and for the 14week-old subjects, F(8/31) = 4.15, p = .002. Table 4 presents the correlations between the baseline measures and the heart rate response separately for the two ages. The extent of sinus arrhythmia was significantly negatively correlated with the heart rate response of the 20-week-old infants for all three phases of habituation on which attention was occurring, indicating that large amounts of sinus arrhythmia index large decelerations. The coherence of sinus arrhythmia and the weighted coherence were also related to both 14 and 20-week-old heart rate responses, albeit sporadically across the habituation phases.

Respiration frequency and respiration amplitude used as covariates were significantly related to the 20-week-old infants' heart rate responses, F(18/89) = 5.03, p < .001, and only approached statistical

Richards

Table 4

Correlations between heart rate change and baseline heart rate variability measures, and physiological responses for the phases of habituation of attention

	Correlations					
	14-Week-Old Infants			20-Week-Old Infants		
Measures	First Three Trials	Response Recovery Trials	Dishabituation Trials	First Three Trials	Response Recovery Trials	Dishabituation Trials
		Baseline	Measures	bre bet too		
Heart Rate	127	192	251*	113	- 068	- 149
Heart Rate Variance	220	.041	281*	.173	- 319*	- 194
DC to .12 Hz Power	.017	.147	.302*	.026	105	- 158
.12 to .24 Hz Power	.163	.156	.246	087	.042	162
.24 to .36 Hz Power	.140	079	225	022	.170	- 221
Extent of Sinus Arrhythmia	.023	184	.016	308*	- 375**	- 357**
Coherence of Sinus Arrhythmia	266*	263*	102	256*	.054	- 141
Weighted Coherence	263*	162	360*	172	.042	050
		Physiologic	al Responses			
Respiration Frequency	165	003	.286*	.312*	.373**	.467**
Respiration Amplitude	.109	202	.213	.052	.021	506**

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

significance levels for the 14-week-olds (p = .078). The respiration frequency responses of the 20-weekolds were negatively correlated with the heart rate responses for all three habituation phases on which attention occurred (Table 4). Respiration amplitude was positively correlated with the heart rate response on the dishabituation trials. The 14-weekold infants showed a similiar pattern of correlations, but with low, nonsignificant values (Table 4). When the covariance adjustment for the respiratory variables was made in the ANOVA for the 20-weekold infants, the constant term was no longer significant. This implies that in the 20-week-olds the heart rate changes taking place during attention were coincident with the respiration changes, whereas the heart rate responses of the 14-week-old subjects were independent of respiratory responses.

Discussion

The usefulness of the prediction of individual differences in cardiac responsivity with baseline cardiac variability level was substantially confirmed by the results of this study. The extent of sinus arrhythmia during the baseline predicted the level of cardiac responses for the data combined over the two ages and for the 20-week-old infants on all phases of habituation. The coherence of sinus arrhythmia, or the weighted coherence measure, was correlated with the heart rate response of the younger age infants on the three phases of habituation during which attention occurred. Thus, respiratory sinus arrhythmia measured in the baseline predicts both individual differences in cardiac responsivity within ages, and developmental differences across ages.

A second manner in which differences in the level of cardiac variability may index cardiac responses during attention is by measuring the level of the potential influence of respiratory attention responses on heart rate attention responses. Since respiratory sinus arrhythmia increases in the age range of the subjects used in the present study, one should predict an increasing coincidence of respiratory and heart rate responses during attention with age. That was indeed the case. The respiration frequency responses for the three phases of habituation on which attention occurred were significantly related to the heart rate response for the 20-weekolds but not for the 14-week-old infants. Additionally, the heart rate response of the 20-week-old infants was not significantly different from zero after covarying for the respiratory responses. In the covariance analysis, the heart rate response of the 14week-olds was independent of the respiration response. This is consistent with the hypothesis that the changes in cardiac responses occurring over this age range, such as the increasing sensitivity of the cardiac decelerative response, are partially due to the increasing effect that respiration responding has on heart rate responding.

The interpretation of these results as unambiguous support for the measurement of cardiac responsivity with cardiac variability is limited by the 14-week-old infants' heart rate responses. Heart rate deceleration rather than acceleration is generally associated with sustained and phasic attention (e.g., Graham & Clifton, 1966). Thus, for the 20-weekold infants, baseline cardiac variability predicts the *attentional* response of heart rate deceleration. However, for the 14-week-old infants, the level of

cardiac variability actually predicted the level of the accelerative response, with higher variability being related to smaller accelerations of heart rate. It may be that in this age group there was a decelerative response overlaid on a stronger accelerative change, and baseline variability predicts the strength of the amelioration of the accelerative response. However, that interpretation is not testable in this study. The weaker relationship between respiratory and heart rate responses for the 14-week-olds may also be due to the accelerative response of heart rate during the periods of visual fixation.

The accelerative response of heart rate of the 14week-old group was unexpected given previous research. Previous studies, using continuous auditory stimuli, have reported small cardiac decelerations by 6 weeks of age and larger decelerative responses by 12 to 16 weeks of age (e.g., Berg, 1972, 1974). Two possibilities may account for the difference between the results of the current study and previous studies. One reason is that almost all of the studies with infants of less than 4 months of age, excluding the neonatal period, have used auditory rather than visual stimuli. It is possible that the cardiac decelerative response to stimulation has a different developmental course for auditory than for visual stimuli. Outside of the neonatal period, the earliest age that has been studied for heart rate responses to visual stimuli was found in a study done with 4-month-old infants (Keen, 1974, cited in Berg & Berg, 1978), which reported similar results to the results of the older age group in the present study.

A second reason that may account for the difference between the present and previous studies of infant heart rate responses is the use of different experimental techniques. Studies using auditory presentations have presented stimuli non-contingent with infant behavior, typically with random interstimulus intervals. The preferred technique for studies of infant visual attention and habituation has been the "infant control procedure," in which the presentation and duration of the stimulus are controlled by the visual fixation by the infant. In the present study, the beginning of fixation on the stimulus most likely was preceded by a head movement since the infant was fixating at the blinking light on the opposite side of the stimulus panel. This movement may have produced a phasic acceleration of heart rate which was overlaid on the expected decelerative response due to fixation. Thus,

the weaker heart rate deceleration expected in the 14-week-olds was completely eliminated, whereas a decelerative response was still evident in the 20week-olds. On the other hand, it is possible that this technique taps a different attentional response than does the methodology used with auditory stimuli. It is the infant rather than the experimenter that controls the beginning and duration of the stimulation in the infant control procedure. The resultant response may therefore reflect a subjectinitiated, controlled attention process, such as the "sustained attention" described by Porges (1976). If this is the case, then the results of the study show that there is a developmental increase in the active allocation of attentional resources from 14 to 20 weeks of age, which is seen in respiration frequency, amplitude, and heart rate responses.

The correlations between the extent of sinus arrhythmia in the baseline and visual fixation durations suggest that cardiac variability measures index general attentional capacity rather than restricted heart rate responsivity. The fact that the fixation durations were shorter for the older infants suggests that they are processing the information in the stimulus faster than are the younger subjects. Respiration amplitude and the level of respiratory sinus arrhythmia were inversely correlated with the fixation duration. Thus, the physiological parameters may be indices of information processing efficiency. This result is consistent with the idea that respiratory sinus arrhythmia in heart rate is an index of a physiological system underlying general attentional capacity (e.g., Porges, 1976; Porges et al., 1982). Since it is well established that respiratory sinus arrhythmia indexes vagal tone, a likely candidate for the underlying physiological system must be related to cholinergic processes in the autonomic nervous system. Whether this system is the "cholinergic nervous system," as postulated by Porges, or a general brainstem system involved in the control of attention, was not differentiated by the results of the present study. However, these results in a developmental paradigm serve as a useful model for studying the prediction of individual differences in attention. As such, they parallel similiar work with pathological populations, who also show naturally occurring levels of respiratory sinus arrhythmia which may be related to attention deficits (Porges et al., 1981; Porges, Walter, Korb, & Sprague, 1975; cf. Porges, 1976; Porges et al., 1982).

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