# Infant Visual Sustained Attention and Respiratory Sinus Arrhythmia

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RICHARDS, JOHN E. *Infant Visual Sustained Attention and Respiratory Sinus Arrhythmia.* CHILD DEVELOPMENT, 1987, 58, 488–496. Infants were studied cross-sectionally at 14, 20, and 26 weeks of age. They were presented with varying and complex patterns on a TV screen. Two-thirds of the presentations were accompanied by an "interrupting stimulus" in the periphery delayed in time from the onset of fixation on the central stimulus. The infants were not easily distracted from looking at the central stimulus when the presentation of the interrupting stimulus occurred at the point of maximal heart rate (HR) deceleration. However, if the presentation occurred at the end of the HR response, the infants were easily distracted. Infants with large amounts of respiratory sinus arrhythmia (RSA; i.e., HR variability) in a baseline recording were less distractible during the deceleration-defined trials than were infants with low amounts of RSA. High-RSA infants also showed larger HR deceleration on these trials than did the low-RSA infants. These results are consistent with a model positing that sustained HR lowering during visual fixation is an index of active attention and that RSA is an index of voluntary, sustained attention in infants.

It has been well documented that heart rate (HR) variability is related to infant attentional responses. Newborns with high levels of HR variability have shown greater HR responses to visual and auditory stimuli than have newborns with low levels of HR variability (Porges, Arnold, & Forbes, 1973; Porges, Stamps, & Walter, 1974; Vranekovic, Hock, Isaac, & Cordero, 1974; Williams, Schacter, & Tobin, 1967). Recently, it has been shown with older infants that the specific type of HR variability related to infant attentional responses is respiratory sinus arrhythmia (RSA), which is variability in HR that occurs at the same frequency as breathing. The changes in HR include acceleration shortly after the beginning of inspiration and deceleration shortly after the beginning of expiration. Level of RSA has been shown to be positively correlated with HR deceleration in a visual habituation task (Richards, 1985a), a task measuring HR responses during sustained visual attention (Richards, 1985b), and an infant memory task (Linnemeyer & Porges, 1986). Level of RSA was also related in those studies to behavioral measures of attention, such as duration of visual fixation (Richards, 1985a, 1985b) and performance on a memory task (Linnemeyer & Porges, 1986).

An empirical description of RSA is that HR accelerates and decelerates at the same frequency as respiration inspiration and expiration. The HR acceleration-deceleration pattern is slightly out of phase with the respiration inspiration-expiration pattern, being delayed by several degrees of the cycle. This co-occurrence of respiration and HR is partially caused by rhythmic activity in the brain stem respiration centers (Grossman, 1983; Lopes & Palmer, 1976; Spyer, 1979). Brain stem control of RSA is mediated via the tenth cranial nerve (commonly called the vagus nerve) by efferent innervation to the heart (Anrep, Pascual, & Rossler, 1935; Katona & Jih, 1975; Porges, McCabe, & Yongue, 1982). The level of overall HR variability varies from person to person, being as small as 2 or 3 bpm and as great as 20–25 bpm in young infants (Harper, Hoppenbrouwers, Sterman, McGinty, & Hodgman, 1976). The level of HR variability due to RSA varies from individual to individual, ranging from as small as 0 or 1 bpm to as great as 10–15 bpm within a respiratory cycle (Harper et al., 1978).

A theoretical explanation for the relation between RSA and infant attentional responses has been offered by Porges in several articles (Porges, 1974, 1976, 1980; Porges, McCabe, & Yongue, 1982). Porges distinguishes between "reactive" and "sustained" attention. Reactive attention is involuntary, phasic, reacts to the onset of a stimulus, and lasts only for about 5 or 6 sec. Sustained attention consists of voluntary, active responses to

This research was supported by grant 1 R23 HD18942-01A1 from the National Institute of Child Health and Human Development. Requests for reprints should be sent to John E. Richards, Department of Psychology, University of South Carolina, Columbia, SC 29208.

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stimulation, begins after reactive attention, and facilitates information and stimulus processing. Porges argues that the varying levels of RSA from individual to individual are an index of individual differences in vagal tone. Since the action of the vagus on the heart is mediated via acetylcholine, vagal tone is indirectly an index of the level of cholinergic activity in the nervous system (both central and peripheral). He also 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. Individual differences in sustained attention should therefore be related to individual differences in level of RSA, since the latter is indexing a functional central nervous system characteristic that is involved in the control of sustained attention.

There is, for young infants, empirical support for the indexing of sustained attention by RSA. Richards (1985b) presented infants of 14–26 weeks of age with a central stimulus that was interrupted on some trials with an interesting peripheral stimulus. The interrupted-stimulus task parallels the dual task paradigm that has been used with adults (Dawson, Schell, Beers, & Kelly, 1982) and older children (Schiff & Knopf, 1985). Subjects should not be distracted by the interrupting peripheral stimulus (secondary task) if they are attending to, or actively processing, the central stimulus (primary task), but they should be easily distracted if they are not attending. It was found that the HR response on the interrupting-stimulus trials was sustained throughout the period of fixation on the central stimulus, indicating that active attention (lack of distraction) coincided with sustained HR responses. The level of RSA from a baseline recording was uncorrelated with the level of HR deceleration during the first few seconds (sec 1–5) of visual fixation but was significantly correlated with the level of HR slowing during later periods (sec 6–10) of visual fixation. From 14 to 26 weeks of age there was also a significant increase in the duration and depth of the deceleratory response during the interrupted-stimulus trials. The results of this study are consistent with the contention that individual differences in sustained attention are indexed by differences in RSA level. It also appears that the older infants are engaged in sustained attention for a longer period of time than the younger infants.

An untested assumption made by Richards (1985b) was that HR deceleration during the long latency period of the interrupted-stimulus trials was evidence that cognitive processing still was occurring. Since not much is known about the psychophysiological components of sustained attention in infants, this assumption may be unwarranted. This assumption was tested in the present study. The interrupting stimulus was presented on some trials when HR deceleration was occurring and on some trials when HR was returning to prestimulus levels. If sustained HR response is coincident with active attention, then the infant should be less distractible when HR deceleration is occurring than when acceleration is occurring. The HR-attention relation was also studied correlationally by presenting the interrupting stimulus at a 3- or 7-sec delay after the onset of fixation on the primary stimulus and then comparing distraction time on trials when HR was significantly below prestimulus level to that on trials when it was at or above prestimulus levels. These two conditions were used to control for the different times that stimulus presentation occurred on the HR-deceleration and HR-acceleration trials. The 3-sec condition also corresponds to the period of "reactive" attention, and the 7-sec condition corresponds to the period of "sustained" attention, as postulated by Porges (1976, 1980). Presenting the interrupting stimulus at different delays may provide a test of the position that reactive and sustained attention (Graham, 1979; Porges, 1976, 1980; Richards, in press) follow a systematic time course. The infant's level of RSA was recorded in a baseline period in order to relate it to HR and fixation responses.

The subjects for the study were 14-, 20-, and 26-week-old infants. These ages may be a "model preparation" for testing the theories of the indexing of attentional responsivity with RSA, since developmental changes in HR variability occur during this time period (see, e.g., Harper et al., 1976). Of most interest, HR variability owing to RSA increases during this age period (Harper et al., 1978; Katona, Frasz, & Egbert, 1980; Richards, 1985a, 1985b; Watanabe, Iwase, & Hara, 1973). Also, Richards (1985b) found that the sustaining of the HR response throughout the entire period of visual fixation increased over this age range. Therefore, this age period may show within-ages RSA-attention relations that parallel across-age RSA-attention relations.

## Methods

### *Subjects*

Infants were recruited for this study from birth notices in a Columbia, South Carolina, newspaper. The infants were full-term, defined as having birthweight > 2,500 grams and gestational age ⩾ 38 weeks as determined by the mother's report of her last menstrual cycle. The parents reported no pre- or perinatal medical complications. A cross-sectional design was used to sample 30 infants each at ages 14, 20, and 26 weeks. The mean testing ages of these three groups of infants were 100.5 days (SD = 3.25), 141.3 days (SD = 3.64), and 183.3 days (SD = 2.31), 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). Fourteen 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 TV monitor (19-inch TV). A single light-emitting diode (LED) was located on the bottom center of the TV screen and blinked at a rate of 3.33 hertz when turned on. The area around the TV monitor was covered with a neutrally colored cloth in order to block extraneous visual information. A video camera lens was located above the TV, and a monitor located in an adjacent room was used by an observer to record infant fixations.

The primary stimuli were three patterns shown on the TV monitor. All stimuli were presented in a 30-cm$^2$ area on the monitor, subtending an approximately 32° visual angle. One stimulus was a recording of a "Sesame Street" TV program; the second was a computer-generated checkerboard pattern of 1.27-cm checks (3° visual angle per check) that alternated black and white areas at 2 hertz. The third pattern was a series of computer-generated, concentric squares. The initial square was the smallest, being 7 cm wide and having a visual angle of 15°. Larger and larger squares were presented until a 30-cm area was filled, and then the squares vanished in sequence, from the outermost to the innermost. These three patterns had been found in pilot testing to elicit initial durations of visual fixation ⩾ 10 sec for the three testing ages. The interrupting stimuli for the interrupted-stimulus trials consisted of two 17 × 11-cm panels that were located 42 cm (38° visual angle) to either side of the center of the screen. These panels had 20 LEDs that blinked on and off at 16 hertz in a sequential pattern resembling a circle, with the circle being completed approximately each second.

### *Procedure*

The RSA was recorded for a 5-min period during which the infant was seated on the parent's lap on a couch. The parent was then seated in the chair with the child on the lap facing the screen. The LED panels were presented for four trials in order to acquaint the infant with their location. Each trial consisted of a 5-sec period with no stimulus followed by the presentation of an LED panel. The infant-control procedure for stimulus presentations (Cohen, 1972; Horowitz, Paden, Bhana, & Self, 1972) was used such that the panel remained on only as long as the infant was looking at it, and the trial was terminated when the infant looked away from the panel.

There were 12 experimental trials, consisting of four *infant-control* trials and eight *interrupted-stimulus* trials. The infant-control trials consisted of the presentation of the primary stimulus until the infant looked away from it. The interrupted-stimulus trials consisted of the presentation of the primary stimulus and the presentation of one of the interrupting stimuli at a delay after the onset of visual fixation on the primary stimulus. The time of the onset of the interrupted stimulus on the interrupting-stimulus trials was based on one of the following four criteria: (1) *3-sec*—presented when 3 sec had elapsed; (2) *7-sec*—presented when 7 sec had elapsed; (3)*HR deceleration*—presented when a significant deceleration of HR had occurred; and (4) *HR acceleration*—presented when HR began to return to prestimulus level following an HR deceleration. An HR deceleration was defined as five successive beats with a heart period longer than the median period of the five heart beats preceding the presentation of the primary stimulus. The return of HR to the prestimulus level on the HR-acceleration trials was defined as five successive beats with a heart period shorter than the median period of the five prestimulus heart beats—and must have followed a deceleration.

The 12 experimental trials began with a 5-sec period with no stimulus, and then the blinking light at the bottom center of the TV was turned on. One of the primary stimuli was presented when the infant looked in the direction of the blinking light. Both HR-deceleration and HR-acceleration trials were restarted if a deceleration did not occur within 10 sec of fixation onset. Interrupted-stimulus trials were restarted if the infant looked away before the onset of the interrupting stimulus. A 5-sec period followed the primary stimulus, with the interrupting stimulus being presented on the interrupted-stimulus trials and no stimulus being presented for the infant-control trials. Two six-trial blocks were used, each with two infant-control trials and one trial from each of the four types of interrupted-stimulus criteria, the procedure order being randomly chosen within each six-trial block. The three primary stimuli were each presented within four three-trial blocks, the order of presentation within blocks being randomly determined.

### *Measurement and Quantification of Physiological Variables*

The electrocardiogram was recorded by placing Ag-AgCl electrodes on the infant's chest with disposable electrode collars. Beat-to-beat intervals were computed on-line with an Apple IIe microcomputer by identifying the R-wave of the electrocardiogram and measuring R-R intervals with 1-msec resolution. The on-line evaluation of HR during HR-deceleration and HR-acceleration trials was made with an Apple IIe having a co-processor board that, based on an 8088 central processing unit, made the evaluation within 5 msec of the criterion beat. For quantitative analyses, the beat-to-beat heart-period intervals were converted to rate (bpm) by assigning values to equal intervals based on the number of beats during the interval weighted by the proportion of time that the beat occupied the interval. The interval duration to which HR values were assigned was 100 msec for the baseline period (0.1-sec × 0.1-sec HR intervals) and 500 msec for the experimental trials (0.5-sec × 0.5-sec HR intervals) (see Graham, 1978). Rate rather than period was chosen as the cardiac function with which 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 on-line at 50 hertz with an Apple IIe computer. Respiration frequency was quantified for each baseline minute by detecting the number of breaths that occurred during each minute. Respiration frequency was quantified only for the baseline period, in order to determine the modal respiration frequency for the quantification of RSA.

A measure of RSA was computed, with spectral analysis methods, from the baseline recording. The extent of RSA was defined as the power of HR summed over a frequency range of 0.1953 hertz (11.71 breaths/min) and centered at the modal respiration frequency for that baseline period (Richards, 1985b; see Harper et al., 1978, and Porges et al., 1982). For the data analysis this power measure was transformed by the natural logarithm function. The metric for extent of RSA is the natural logarithm of the root-mean-squared variation of HR at the respiration frequency ranges. The HR power spectrum was computed from HR values assigned to 0.1-sec intervals, and the respiration signal was sampled at 0.1-sec intervals. The first 512 0.1-sec intervals of each of the minutes were used, giving a frequency resolution of 0.01953 hertz. The value was extracted separately from the data for each period and was averaged over these 5 baseline min.

### *Experimental Design for Statistical Analysis*

The results were analyzed in a factorial design. Testing age was a between-subjects factor, and the procedure (HR-deceleration, HR-acceleration, 3-sec, 7-sec, and infant-control trials), and intervals (0.5-sec × 0.5-sec periods) were within-subject factors. The first of the two infant-control trials in each of the two six-trial blocks was used for data analysis in order to have an equal number of trials in each of the levels of the procedure factor (two trials per level). Only the variation due to the linear, quadratic, and cubic trends of the intervals factor was analyzed and reported, since often only the lower-order trends are of interest—or are interpretable—in the context of HR research. The statistical significance of the intervals effect was based on the multivariate approach to testing repeated measures (McCall & Appelbaum, 1973; O'Brien & Kaiser, 1985), since repeated physiological measures may violate some of the assumptions of the univariate ANOVA procedure. Post-hoc comparisons were done using the Scheffé test to control experimentwise error rate. The potential trials factor (due to the use of two six-trial blocks) was not of direct relevance to the study and so was not tested in the analysis. Extent of RSA was used as a between-subject factor by performing a median split within each testing age on the measure and separating subjects into low and high groups. The medians of the natural logarithms of the root-mean-squared variabilities of HR at the respiration frequency—the medians of the natural logarithms of the root-mean-squared extent of the RSA—were 1.784, 2.247, and 2.663 for the 14-, 20-, and 26-week-olds, respectively.

## Results

### *Heart Rate*

*Onset response.*—The HR onset response was analyzed as the difference between the 0.5-sec values of HR during the first 5 sec of the central stimulus and the 2.5-sec prestimulus mean. This change score was analyzed with an Age (3) × Extent of RSA (2) × Procedure (5) × Intervals (10) ANOVA. There was a main effect of intervals on the HR response, $F(3,82) = 67.11$, $p < .001$. All three polynomial trends were significantly affected ($p$'s $< .001$). There was a large deceleration of HR for all procedures, and the pattern of the response was the same for all procedures (i.e., there was no procedure × intervals interaction). The pattern of the response was similar to that found in other studies with similar stimuli (see, e.g., Richards, 1985b) and so is not shown. There was also a main effect of procedure on the HR response, $F(4,336) = 3.60$, $p < .01$. Post-hoc comparisons showed that the level of the HR response was the greatest for the HR-deceleration and HR-acceleration procedures ($M$'s $= -4.93$ and $-4.25$ bpm; not significantly different). Those means were significantly different ($p < .05$) from the means on the 3-sec, 7-sec, and infant-control trials ($M$'s $= -3.24$, $-3.61$, and $-2.88$ bpm, respectively; not significantly different). There were no other main effects or interactions significantly affecting the onset of HR response.

*Preceding and following interrupting stimulus.*—The HR pattern for the 2.5-sec period preceding and following the onset of the interrupting stimulus was analyzed as the difference between the 0.5-sec values of HR during this period and the mean HR during the 2.5-sec pre–central stimulus period. This change score was analyzed with a Procedure (4) × Intervals (10) ANOVA, using data only from the four interrupted-stimulus procedures, to determine whether the experimental manipulations involving the physiological variables had the desired effect. There were significant procedure, intervals, and procedure × intervals effects on the HR response during this period. Of these, the procedure × intervals effect, $F(9,81) = 53.80$, $p < .001$, was of main interest. Figure 1 shows the HR response for the four procedures for the 2.5-sec period preceding and following the onset of the interrupting stimulus. Post-hoc tests showed that all three polynomial trends were significantly affected for the HR-acceleration and HR-deceleration trials ($p$'s $< .001$). There was a deceleration of HR on the HR-deceleration trials during this period and an acceleration of HR on the HR-acceleration trials (Fig. 1). This was expected, since the onset of the interrupted stimulus was experimentally presented contingent on changes in HR on these trials. The linear ($p < .001$) and quadratic ($p < .05$) trends were significantly affected for the 3-sec trials, but none of the polynomial trends were significantly affected for the 7-sec trials. The HR was decelerating from the prestimulus level for the 3-sec trials (overlapping the HR onset response) and was lower than prestimulus level but stable on the 7-sec trials (Fig. 1).

The mean-HR-difference score from the 2.5-sec period following the onset of the interrupting stimulus was analyzed with an Age (3) × Extent of RSA (2) × Procedure (4) ANOVA. The HR from this period was analyzed because HR should be a physiological

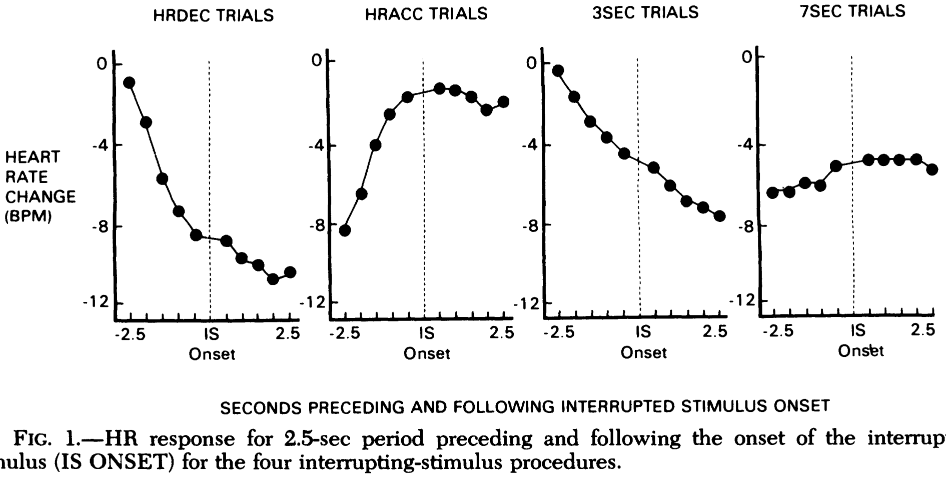

FIG. 1.—HR response for 2.5-sec period preceding and following the onset of the interrupting stimulus (IS ONSET) for the four interrupting-stimulus procedures.

index of cognitive-processing status at that moment and should complement the behavioral index of cognitive processing, distraction time (see following section). There was a significant effect of procedure on the HR response, $F(3,252) = 35.75$, $p < .001$. This effect parallels the procedure effect reported in the previous analysis. There was a significant interaction of extent of RSA and procedure on the HR response during this period, $F(3,252) = 2.96$, $p < .05$. A simple main-effects analysis of the extent of RSA effect for the four interrupted-stimulus procedures revealed that the extent of RSA factor significantly affected the HR response on the HR-deceleration trials ($p < .01$) but not that for any of the other procedures. Infants with a low magnitude of RSA in the baseline showed an average HR change of −7.67 bpm on the HR-deceleration trials, and infants with a large magnitude of RSA in the baseline showed an average HR change of −11.30 bpm on these trials.

There was also a significant interaction of extent of RSA and age on the HR response during the post–onset-of-interrupted-stimulus period, $F(2,84) = 4.07$, $p < .05$. Averaged over the interrupted-stimulus procedures, the HR response difference for the low and high extent-of-RSA infants was different at the three testing ages, although all were in the same direction (high extent of RSA with larger HR deceleration than low extent of RSA). To look at this effect another way, the mean HR response of the infants with a low magnitude of RSA was not significantly different across the three testing ages (*M*'s = −3.95, −5.62, −4.87 bpm for 14-, 20-, and 26-week-olds, respectively). However, there was a significant increase in the magnitude of the HR response over this age period for the high-magnitude-RSA infants ($p < .05$; *M*'s = −4.51, −6.46, −7.47 bpm for 14-, 20-, and 26-week-olds, respectively).

### *Distraction Time*

The duration from the onset of the interrupted stimulus until the look toward it (distraction time) was analyzed with an Age (3) × Extent of RSA (2) × Procedure (4) ANOVA for the four interrupted-stimulus procedures. The time variable was not normally distributed, so it was transformed by the natural logarithm function, and the transformation resulted in a normally distributed variable. There was a main effect of age on distraction time, $F(2,84) = 24.67$, $p < .001$. The latency to distraction by the interrupting stimulus was the longest for the 14-week-olds, at an intermediate value for the 20-week-olds, and shortest for the 26-week-olds (*M*'s = 6.83, 4.83, and 3.82 sec, respectively). There was also a significant procedure effect, $F(3,252) = 14.85$, $p < .001$, and an extent of RSA × procedure interaction effect, $F(3,252) = 3.51$, $p < .05$. Table 1 shows the means for the distraction times for the four procedures, separated by the high and low extent-of-RSA groups. Table 1 also includes the total duration of fixation on the central stimulus. There are two interesting aspects to the mean distraction times presented in that table. First, a post-hoc comparison test showed that it took significantly longer to distract the infants on the HR-deceleration trials than it did on the HR-acceleration trials ($p < .05$). Second, a simple main-effects analysis of the extent-of-RSA effect for the four procedures showed that on the HR-deceleration trials it took significantly longer to distract the infants having large magnitude of RSA than it did to distract the infants having small magnitude of RSA ($p < .05$).

An analysis of the relation between the HR response and distraction time was done separately for the 3-sec and 7-sec trials. This was done in order to determine whether HR changes and distractibility were coincident when the interrupting stimulus was presented at a fixed point in time rather than being presented contingent on the HR response pattern. Individual 3-sec and 7-sec trials were split within ages according to the HR level in the 2.5-sec period following the onset of the interrupted stimulus. The following three response levels were established: (1) HR less than or equal to that on the average HR-deceleration trial (−9.52 bpm), (2) HR greater than or equal to that on the average HR-acceleration trial (−1.64 bpm), and (3) trials with the HR level between the levels of (1) and (2). These HR levels were chosen to compare the 3-sec and 7-sec trials with the HR-acceleration and HR-deceleration trials. Approximately equal numbers of trials fit in these three categories for the 3-sec and 7-sec trials. Distraction time on the 3-sec and 7-sec trials, split according to HR responses, was analyzed with an Age (3) × Procedure (2) × HR Response Level (3) ANOVA. The only significant effect was the HR-response-level factor, $F(2,342) = 4.04$, $p < .05$. It took longest to distract the infant with the interrupting stimulus when HR was still decelerating, took an intermediate amount of time when the HR response was at an intermediate level, and the shortest time when the HR response was accelerating toward or had returned to prestimulus levels (*M*'s = 6.48, 5.27, and 4.63 sec, respectively).

TABLE 1

MEAN DISTRACTION TIME (sec) FOR THE INTERRUPTED-STIMULUS PROCEDURES

| | PROCEDURE | | | | |
|---|---|---|---|---|---|
| | HR Deceleration | HR Acceleration | 3 Sec | 7 Sec | Infant Control |
| Low extent of RSA: | | | | | |
| Mean | 5.60 | 3.49 | 6.98 | 4.97 | ... |
| SD | (3.54) | (2.93) | (6.36) | (3.29) | |
| High extent of RSA: | | | | | |
| Mean | 7.52 | 3.09 | 5.36 | 4.29 | ... |
| SD | (4.91) | (1.97) | (3.93) | (3.31) | |
| Both groups: | | | | | |
| Mean | 6.58 | 3.29 | 6.15 | 4.63 | ... |
| SD | (5.58) | (2.50) | (5.29) | (3.30) | |
| Total fixation duration: | | | | | |
| Mean | 10.19 | 13.53 | 9.30 | 11.78 | 12.75 |
| SD | (5.63) | (4.33) | (5.29) | (3.30) | (6.09) |

NOTE.—Mean distraction time for the interrupted-stimulus procedures consists of the time from the interrupted-stimulus onset to looking away from the central stimulus, separated by low and high extent of RSA infants. The average total duration of fixation on the central stimulus is presented for all procedures for comparison.

## Discussion

The results of this study are supportive of the assumption of Richards (1985b) that sustained HR response in infants indicates that active processing is occurring. The infants were less easily distracted by the interrupting stimulus when it was presented contingent on HR deceleration than when it was presented contingent on HR returning to prestimulus levels. If the interrupting stimulus was presented at a fixed point in time, infants were less easily distracted if HR deceleration was still occurring than if HR had returned to prestimulus levels. Thus, behavioral (distraction-time) and physiological (HR-response) indices of active cognition were closely linked. The similar ordering of HR response level and distraction time on the 3-sec and 7-sec trials also suggests that level of HR response was positively associated with level of attention. This finding parallels the position of Kahneman (1973) that cognitive-processing intensity—or the amount of cognitive resources dedicated to a task—is paralleled by the magnitude of task-induced changes in the autonomic nervous system.

This study again documents the association between HR variability and attentional responses and supports the theory (Porges, 1976) that RSA is an index of individual differences in infant sustained attention. The RSA was closely related to both the behavioral and physiological indices of attention on the trials in which attention was posited to be the most active (i.e., the HR-deceleration trials). The HR onset response (e.g., reactive attention) was not affected by the extent-of-RSA variable for any procedure. Rather, it was the HR response following the significant HR deceleration on the HR-deceleration trials that was differentiated by extent of RSA, as was the behavioral measure of sustained attention on those trials. The finding of Richards (1985b)—that the sustained HR response in the long-latency period of visual fixation is related to RSA—is complementary support for the contention that it is the sustained and not the reactive component of attention that is indexed by level of RSA.

The separation of infant attention processes into distinct phases based on the time course of HR response may not be entirely accurate. If the approximate times given by Porges (1976) for reactive (1–5 sec) and sustained (> 5 sec) attention are correct, then one might expect that extent of RSA would distinguish HR and distraction-time responses on the 7-sec trials but not on the 3-sec trials. However, the extent-of-RSA variable did not distinguish the responses on these two procedures as it did with the HR-deceleration procedure. Also, the splitting of the 3-sec and 7-sec trials into those with HR deceleration and HR acceleration showed that the HR response level occurring in the presumed reactive attention phase (i.e., 3-sec trials) was associated with the behavioral measure of active attention, distraction time. Both HR level and HR *variability* were postulated by Porges (1976, 1980) to decrease during sustained attention. In the present study only HR response level was investigated, since HR variability is difficult to study in conjunction with attention to the simple stimuli used in this study. Thus, a full test of the sustained versus reactive attention distinction should be made with stimuli that can induce experimentally a consistent visual attention response over large intervals of time.

The question of developmental changes in sustained attention is not so clearly answered by this study. There was a significant decrease in distraction time over the age range used in this study, and similar decreases were found by Richards (1985a, 1985b); however, this decrease did not differ for the four interrupting-stimulus procedures. If the HR-deceleration procedure with the interrupted-stimulus presentation measured sustained attention better than did the other procedures, then age changes in sustained attention would differentially affect distraction time in this procedure vis-à-vis the others. The lack of a developmental change in sustained attention parallels a recent finding of Ruff (1986) with infants aged 6, 7, 9, or 12 months (Experiments 1, 2, and 3). The latency to touch small, graspable objects decreased in the second half of the first year, whereas object examination time did not change with age. Object examination time, which did not change with age, is similar to sustained attention as defined by Porges (1980), since it involves the active encoding of object information.

On the interrupting-stimulus trials there were age changes in the HR response that parallel and amplify the findings of Richards (1985b). Richards found that for an interrupted-stimulus paradigm there was an increasingly sustained HR response for the older-age infants—but only for the interrupted-stimulus and not for the infant-control trials. The age difference in the HR response during the post–interrupted stimulus period of the present experiment was only significant for the infants having high levels of RSA in the baseline recording. Thus, with the increasing age levels used in this study, the HR response occurring during the period when the infant was not distracted by the interrupting stimulus was accompanied by sustained HR response, particularly for the high extent-of-RSA groups. However, as with distraction time, age differences in the response were not differentially affected by the type of experimental procedure. This suggests that the older, high-RSA infants are responding with sustained HR lowering in the trials when active attention is occurring (i.e., in the HR-deceleration trials) as well as when active attention is ceasing and the infants are becoming more distractible (i.e., in the HR-acceleration trials).

The use of the interrupting-stimulus paradigm and the co-occurrence of sustained HR lowering and long distraction times may be profitably compared with a study that used a similar method but studied different components of attention. Anthony and Graham (1983) studied the effects of attention engagement on the blink reflex of young infants. Visual or auditory stimuli were presented that were interesting or dull and resulted in corresponding levels of HR deceleration. A visual or auditory probe that was known to elicit the blink reflex was presented following attention engagement to the primary stimulus. The blink reflex was enhanced when attention was the greatest (i.e., during the interesting stimuli) and when the probe and primary stimulus were in the same modality. The probe engaged a "transient-detection" attention system (Graham, 1979; Richards, in press), whereas the primary stimulus engaged reactive or sustained attention. Thus, a relatively automatic attention process was facilitated by more sophisticated cognitive processing, as least in the same stimulus modality. In the present experiment, the engagement of infant attention on the central task (in the HR-deceleration trials) competed with rather than facilitated the infant's response to the interrupting stimulus. This competition for resources emphasizes the parallel between the interrupting-stimulus methodology used in the present study and the dual-task procedure used in studies with older children and adults.

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