Psychophysiology
Vol. 25, No. 3

Printed in U.S.A.

Heart Rate Offset Responses to Visual Stimuli in Infants from 14 to 26 Weeks of Age

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ABSTRACT

Heart rate offset responses to visual stimuli were studied in infants tested cross-sectionally at 14, 20, and 26 weeks of age. In Experiments 1 and 2, offset responses were measured in each infant following visual stimuli presented with three procedures. The fixed interval method consisted of stimulus presentations of 7 s in duration. The infant control method consisted of stimulus presentations which were terminated when the infant looked away from them. The interrupted stimulus method consisted of stimulus presentations which were terminated when the infant looked away toward an interrupting, secondary stimulus. In Experiment 3 these procedures were compared with two procedures in which stimulus termination occurred at the point of heart rate deceleration or the return of heart rate toward prestimulus level. The stimuli in Experiment 1 were checkerboard patterns, in Experiment 2 were complex and varying stimuli, and in Experiment 3 were either TV stimuli or an overhead light.

The offset responses were similar for the fixed interval and infant control methods, and consisted of brief heart rate decelerations. The magnitude of the heart rate response was generally small (1.5 to 2 bpm), with the largest heart rate response being 4 bpm. The pre-offset heart rate response was similar for the infant control and interrupted stimulus and heart rate acceleration trials, with heart rate showing a return to prestimulus levels immediately preceding subject-controlled fixation termination. Infants with high levels of respiratory sinus arrhythmia (RSA) measured during a 5-min baseline showed larger heart rate offset responses than did low RSA infants. These results call into question the interpretation of heart rate offset responses in the context of Sokolov's model of the orienting response. However, the offset paradigm is useful in the study of subject-controlled attention processes.

DESCRIPTORS: Infancy, Heart rate, Offset response, Respiratory sinus arrhythmia, Visual attention.

Psychophysiologists interested in testing the tenets of Sokolov's (1963) theory about psychophysiological responses have been primarily concerned with the orienting response (OR) which occurs at the onset of low and moderate intensity stimuli. However, Sokolov also claimed that the termination of any stimulus which has caused an orienting response or defensive reflex should produce a response similar to the orienting response, the offset response. This response, for heart rate, should consist of a heart rate deceleration of nearly equal magnitude to the onset response, and should habituate rapidly (Graham & Clifton, 1966).

This research was supported by a grant from the National Institutes of Child Health and Human Development, R23 HD18942.

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Researchers studying the heart rate responses of newborns and young infants have reported heart rate offset responses to varying types of stimuli. Newborns show a 3–4 bpm decrease in heart rate at the termination of both visual (Porges, Stamps, & Walter, 1974; Adkinson & Berg, 1976) and auditory stimuli (Porges, Arnold, & Forbes, 1973). The heart rate offset response to auditory stimuli has been studied in older infants. Berg in several studies (Berg, 1972, 1974; Brooks & Berg, 1979) reports a 2–3 bpm decrease in heart rate at the termination of an auditory stimulus, and Lewis (1971) reports about a 9 bpm decrease. With the exception of the Lewis report, the average level of the heart rate deceleration that occurs at offset is only 2–4 bpm, compared with a 6–12 bpm decrease in heart rate at stimulus onset. The heart rate offset response to visual stimuli has not been studied in infants other than newborns. There are no consistent developmental trends in the heart rate offset response across research studies.

Many studies of the heart rate orienting response in young infants show habituation of the response with repeated stimulus presentation. On the other hand, the heart rate offset response increases in strength with repeated stimulus presentation. Studies of newborns (Porges et al., 1974; Adkinson & Berg, 1976), 6 week olds (Berg, 1974), and 4 month olds (Berg, 1972, 1974; Brooks & Berg, 1979) have reported a progressive increase in the magnitude of cardiac deceleration to stimulus offset with repeated presentations. Only one study (Lewis, 1971) has reported otherwise, finding habituation of the heart rate offset response in 3 month olds, and no change over trials in either 6 or 12 month old infants. Thus, it appears from both the magnitude of the heart rate deceleration response, as well as its lack of habituation, that the offset response of infants is dissimilar to the orienting response, at least for heart rate.

One problem in the studies of the heart rate offset response in infants has been the use of trials of fixed duration. The fixed interval paradigm has several limitations. First, with visual stimuli, the experimenter cannot ensure that the infant is looking at the stimulus at offset, or even has its eyes open. This limitation is not as great with auditory stimuli. A second problem, which applies to both auditory and visual stimuli, is that in the fixed interval presentation the stimulus termination is independent of the subject's behavior. These lead to two problems. The first problem is that the subject may or may not be actively attending at the time of stimulus offset. It is reasonable to expect that differential responding may take place depending on the subject's attention status. Second, an interesting question regarding the end of attention is the understanding of subject-initiated control of attention processes. This is crucial to the understanding of sustained attention (Porges, 1976; Richards, 1988), which is important for actively engaging in information processing. The fixed interval method puts stimulus termination totally under the experimenter's control, whereas the study of subject-controlled attention needs to place stimulus termination partially under subject control. Thus, methods are needed to complement the fixed interval paradigm which investigate the offset response (a) during active attention, (b) at attention termination, and (c) at subject-initiated stimulus termination. These methods may extend the use of the offset paradigm to the study of subject-controlled attention.

Three experiments are reported which were designed to examine the heart rate offset response to visual stimuli in infants from 14 to 26 weeks of age, taking the preceding concerns into account. Experiments 1 and 2 compare the traditional fixed interval paradigm with two subject-controlled offset paradigms. The subject-controlled paradigms are the infant control procedure (Cohen, 1972; Horowitz, Paden, Bhana, & Self, 1972) and the interrupted stimulus procedure (Richards, 1985b, 1987, 1988). In the infant control procedure the stimulus remains on as long as the infant is looking at it, and stimulus termination occurs when the infant looks away. For the interrupted stimulus procedure the primary stimulus remains on until the infant looks away toward an interrupting, secondary stimulus. Both of these procedures represent subject-initiated termination of the stimulus. However, the latter procedure may be a more sensitive measure of sustained attention, since the infant is not distractible as long as it is paying attention to the primary stimulus (Richards, 1987). When attention wanes, the infant is quickly distracted by the interrupting stimulus, eliminating periods of fixation on the stimulus without active processing of it. On the other hand, infants in the infant control condition may continue to fixate on the stimulus even though active stimulus processing has ceased.

In Experiment 3 the fixed interval paradigm is compared with procedures in which stimulus offset occurs at active or inactive attention. It has been posited that infant heart rate may be used to distinguish different types of attention (Graham, 1973, 1979; Porges, 1976, 1980; Richards, 1988). It has been found (Richards, 1987) that during heart rate deceleration to a visual stimulus the infant is less distractible by a secondary stimulus than during the return of heart rate to prestimulus levels. According to limited resource theory, it should be harder to distract the infant by the secondary stimulus if resources are actively committed to the primary stimulus. The implication of this finding is that active attention is assessed physiologically by heart rate deceleration and lasts for several seconds, and inactive attention by the return of heart rate to prestimulus levels (Richards, 1987, 1988). Therefore, in Experiment 3, the status of the information processing system was assessed by ongoing heart rate response patterns, and the heart rate offset responses at active attention and attention termination were studied.

Finally, a measure of heart rate variability due to respiratory activity, respiratory sinus arrhythmia (RSA), is measured in each study because of the possibility of larger heart rate offset responsiveness in infants with large levels of RSA (cf., Porges et al., 1973, 1974). This is interesting because sustained attention level in infants is related to level of RSA (Richards, 1985b, 1987), and therefore may be related to the heart rate offset response occurring for subject-controlled stimulus termination.

EXPERIMENT 1

Methods

Subjects

Infants for this study were recruited from birth notices in a Columbia, South Carolina, newspaper. The infants were full-term, and the parents reported no pre- or perinatal medical complications. A cross-sectional design was used to sample infants at 14, 20, and 26 weeks of age. The mean testing ages of the infants were 99.4 days (SD=3.25), 142.7 days (SD=3.54), and 184.0 days (SD=2.89), respectively. Thirty subjects at each age were used. The testing was done only if the subjects maintained an alert, awake state (eyes open, no fussing or crying, responding to the protocol) during the entire procedure (approximately 30 min total time). Thirteen additional infants did not complete the testing because they did not maintain this state.

Apparatus

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

The stimuli were computer-generated checkerboard patterns. They were presented on the television monitor in a 30 cm (1 ft) square area and were either 2.54, 1.27, or 0.635 cm (1.0, 0.5, or 0.25 in.) in size. The sizes of the checks were chosen from hypothetical developmental changes in pattern preferences (Karmel & Maisel, 1975), and corresponded to the approximate maximum preference for contour density at 8, 14, and 20 weeks of age. The patterns were either presented continuously or changed from black to white at 6.25 Hz. This resulted in six different stimuli. The interrupting stimuli for the interrupted stimulus method consisted of two 17 × 11 cm panels which were located 42 cm to either side of the center of the screen. These panels had 20 LEDs which blinked on and off at 16 Hz in a sequential pattern resembling a circle, with the circle being completed approximately each second.

Procedure

The infant was seated on the parent's lap on a couch for a 5-min baseline period in order to record respiratory sinus arrhythmia. The parent was then seated in the chair with the child on the lap facing the screen. The LED panels were presented for three trials in order to acquaint the infant with their location. The experimental trials consisted of the presentation of the checkerboard patterns. The blinking light at the bottom of the screen was turned on following a 2.5-s period with no stimuli, and a checkerboard pattern was presented when the infant looked in the direction of the blinking light.

The duration of the stimulus was determined on each trial by one of three criteria. The fixed interval (FI) trials consisted of the presentation of the checkerboard pattern for 7 s. The infant control (IC) trials consisted of the presentation of the pattern as long as the infant was looking at it, and the pattern was turned off when the infant looked away from it. The interrupted stimulus (IS) trials consisted of the presentation of the checkerboard stimulus for 5 s by itself, at which time a panel on one side of the monitor was activated. When the infant looked away from the checkerboard pattern toward the interrupting stimulus the checkerboard stimulus was terminated. The trials ended with a 5-s period, with either no stimulus on (IC and FI trials) or the interrupting stimulus on (IS trials). The three presentation methods were given four times to each child, and the six checkerboard stimuli were presented two times each, with the methods and stimuli randomly chosen within three- or two-trial blocks, respectively.

Measurement and Quantification of Physiological Variables

The EKG was recorded by placing Ag-AgCl electrodes on the infant's chest with disposable electrode collars. Beat-to-beat intervals were computed online with an Apple IIe microcomputer by identifying the R-R intervals in the EKG with 1-ms resolution. The beat-to-beat heart period intervals were converted to rate (bpm) by assigning values to equal intervals based on the number of beats in the interval weighted by the proportion of time that the beat occupied the interval. Heart rate was calculated on a 0.1-s by 0.1-s basis for the baseline period and on a 0.5-s by 0.5-s basis for the experimental trials. 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 Apple IIe computer. Respiration frequency was quantified by computing on a breath-to-breath basis the respiration cycle period (20-ms resolution), converting that to rate (breaths per minute), and assigning values to 0.5-s intervals in the same manner as was done with heart rate. Heart rate was recorded in the baseline period as well as during the attention trials. Respiration frequency was quantified only for the baseline periods, in order to determine the modal respiration frequency for the quantification of respiratory sinus arrhythmia. Rate rather than period was chosen as the cardiac function to coordinate the heart response with fixation patterns in the experimental trials (Graham, 1978; Richards, 1980).

A measure of respiratory sinus arrhythmia derived from spectral analysis methods was computed for the baseline period. The extent of respiratory sinus arrhythmia (RSA) was defined as the power of the heart rate spectrum at the modal respiration frequency for that baseline period (Richards, 1985a, 1985b, 1987; cf. Harper et al., 1978; Porges, McCabe, & Yongue, 1982). 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 periods were used, giving a frequency resolution of 0.01953 Hz. The heart rate power spectrum was computed from the Fast Fourier Transform, with a modified Daniell smoothing algorithm being used to obtain the power spectrum from the periodogram (Bloomfield, 1976). The value was extracted separately from the data for each baseline minute, and was averaged over these five baseline periods.

Experimental Design for Statistical Analysis

The results were analyzed in a factorial design. Testing age was a between-subjects factor, and the procedure (fixed interval, infant control, and interrupted stimulus trials) and intervals (0.5-s by 0.5-s periods) were within-subjects factors. The statistical significance of the intervals effects was based on the Greenhouse and Geisser (1959; see Richards, 1980) proportional *epsilon* adjustment, since repeated physiological measures may violate some of the assumptions of the ANOVA procedure. *Post hoc* comparisons were done using the Scheffé test to control experimentwise error rate. The three periods of the experimental trials (onset, pre-offset, offset) were analyzed separately. The potential trials factor (four 3-trial blocks) was not of direct interest to the aims of the study, and so was not tested in the analysis. Extent of RSA was used as a between-subjects factor by performing a median split within each testing age on the measure, and separating subjects into low and high extent of RSA. As with previous studies (e.g., Richards, 1985b, 1987), RSA level increased over the three testing ages for subjects in all three experiments.

Results

Fixation Duration

The duration of the checkerboard stimulus was analyzed with an Age(3) × Extent of RSA(2) × Procedure(3) ANOVA. There were significant effects of procedure, $F(2/168)=44.76$, $p<.001$, and testing age, $F(2/84)=38.33$, $p<.001$, on stimulus duration. As defined, stimulus duration was 7 s on the fixed interval (FI) trials. Fixation durations on the infant control (IC) trials were significantly longer than on the interrupted stimulus (IS) trials ($\overline{X}$'s = 10.1 s and 8.82 s). On both IC and IS trials, the 14 week olds looked the longest times ($\overline{X}$'s = 13.02 and 11.35 s), the 20 week olds for an intermediate duration ($\overline{X}$'s = 9.68 and 8.0 s), and the 26 week olds for the shortest duration ($\overline{X}$'s = 7.62 and 7.12 s). The Procedure × Age interaction was not significant when only the IC and IS trials were included in the analysis, indicating that the IC/IS duration difference was not significantly different across the three ages.

Heart Rate Onset Response

The heart rate onset response was analyzed as the difference between the 0.5-s values of heart rate during the first 5 s of the stimulus presentation, and the 2.5-s prestimulus mean. This change was analyzed with an Age(3) × Extent of RSA(2) × Procedure(3) × Intervals(10) ANOVA. The only significant effect from this analysis was an intervals main effect, $F(9/756)=38.05$, $p<.001$. Heart rate showed a significant deceleration of 5–6 bpm, which did not differ for the ages, procedures, or extent of RSA groups. The pattern of heart rate change was almost identical to that found by Richards (1985b), and others, and so is not illustrated here.

Heart Rate Pre-Offset Response

The pattern of heart rate values during the 5 s immediately preceding the termination of the stimulus was analyzed as the difference between the 0.5-s values and the 2.5-s prestimulus mean value. This difference was analyzed with an Age(3) × Extent of RSA(2) × Procedure(3) × Intervals(10) ANOVA. These heart rate values were significantly affected by the intervals main effect, $F(9/756)=24.0$, $p<.001$, the Procedure × Intervals interaction, $F(18/1512)=2.44$, $p<.05$, and the Age × Procedure × Intervals interaction, $F(36/1512)=2.15$, $p<.05$. Figure 1 shows the heart rate difference from the prestimulus period for the three procedures for both the pre-offset and the offset periods. The heart

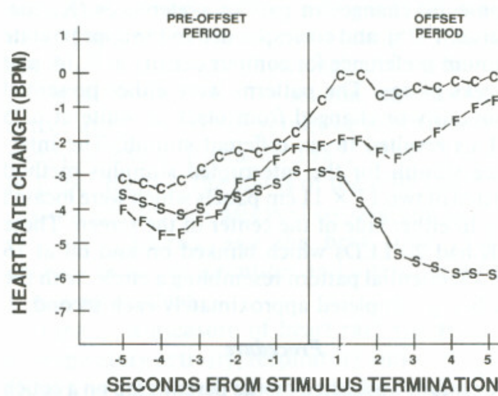


Figure 1. Average heart rate difference between the prestimulus and the pre-offset and offset periods for fixed interval (F), infant control (C), and interrupted stimulus (S) trials for Experiment 1.

rate pattern on the fixed interval (FI) trials included decreasing heart rate at the beginning of the pre-offset period, with a sharp turn toward the prestimulus heart rate level by the middle and end of the period. Heart rate was increasing toward the prestimulus level on the infant control (IC) trials. The pattern of the interrupted stimulus (IS) trials was similar in form to the FI trials, but heart rate was only beginning to return to prestimulus levels before fixation was terminated. For the FI trials, the heart rate level for all three ages was nearly equal in the beginning of the pre-offset period (approximately −5 bpm from prestimulus level). However, the 26-week-old heart rate level returned to the prestimulus level by the end of the pre-offset period (−0.5 bpm difference), the 20-week-old heart rate level to an intermediate level (−2.0 bpm difference), and the heart rate of the 14 week olds still remained relatively low (−3.75 bpm difference).

There was a significant effect which did not involve the intervals factor, the Age × Extent of RSA × Procedure effect, $F(4/168)=2.9$, $p<.05$. However, since it did not involve the intervals factor it was not directly relevant to the concerns of the study, and is not further discussed.

Heart Rate Offset Response

The pattern of heart rate values during the 5 s immediately following the stimulus termination was analyzed as the difference between the 0.5-s heart rate values and the mean heart rate value from the 2.5-s prestimulus period. This difference was analyzed with an Age(3) × Extent of RSA(2) × Procedure(3) × Intervals(10) ANOVA. There were three significant effects which were all based on the pattern of responding in the three procedures. These included a significant procedure effect, $F(2/168)=23.13$, $p<.001$, an intervals effect, $F(9/756)=7.92$, $p<.001$, and a Procedure × Intervals interaction, $F(18/1512)=16.86$, $p<.001$. Figure 1 shows the heart rate response during the offset period for the three experimental procedures. On both infant control (IC) and fixed interval (FI) trials, there was a brief (<2 s) and small (<1.5 bpm) heart rate deceleration at the offset of the visual stimulus (Figure 1). However, for the IC trials, the heart rate had completely returned to the prestimulus level before this deceleration occurred. For the interrupted stimulus (IS) trials, heart rate was beginning to return to prestimulus levels in the pre-offset period, and decelerated sharply in the offset period when the infant was fixating on the interrupting stimulus (Figure 1).

The heart rate level in the offset period was significantly affected by an Extent of RSA × Procedure × Intervals interaction, $F(18/1512)=2.34$, $p<.05$. The simple interaction of Extent of RSA × Intervals was significant for both the IC and the FI procedures (p's$<.05$). For both procedures, the heart rate of the low RSA group continued to increase at the offset of the stimulus, whereas the heart rate in the high RSA group showed a significant deceleration at stimulus termination. Thus, most of the offset response illustrated in Figure 1 for the IC and FI procedures was due to the high RSA infants. The simple interaction of Extent of RSA × Intervals within the IS procedure was *not* significant, indicating no differences in the heart rate pattern for the two RSA groups when viewing the interrupting stimulus.

Discussion

The checkerboard stimuli for the first experiment had check sizes that were based on hypothetical developmental changes in pattern preferences for these ages (Karmel & Maisel, 1975), and had been used in Richards (1985a, 1985b). It was thought that these stimuli would evoke a range of attention levels at the different ages. However, the average viewing time of the oldest infants was approximately 7 s, corresponding to the duration of the fixed interval (FI) trials in Experiment 1. The differential return to prestimulus heart rate levels in the pre-offset period for the three ages on the FI trials was likely due to differential attention engagement/disengagement for the three ages. That is, the offset response on the FI trials for the 14 week olds came during full attention engagement, during partial attention engagement for the 20 week olds, and during attention disengagement for the 26 week olds. In Experiment 2, stimuli were used which resulted in average viewing times for the three ages which were much longer than 7 s. Therefore, the FI offset response should occur during full attention engagement for all three ages.

EXPERIMENT 2

Methods

Subjects

The procedures for procuring and using subjects was identical to Experiment 1. The mean testing ages of the infants were 100.7 days (SD=3.86), 142.0 days (SD=2.30), and 184.5 days (SD=3.77), respectively. Ten subjects at each testing age were used. Four additional subjects did not complete the testing protocol because they did not maintain the alert, awake state.

Apparatus and Procedure

The presentation apparatus was identical to that of Experiment 1. Three stimuli were used as primary viewing stimuli. One was a checkerboard pattern of

1.27 cm checks which changed from black to white at 6.25 Hz (medium complexity level of Experiment 1). The second pattern was a video recording of a Sesame Street television program. The program was run continuously from the beginning during the experimental trials, and so the infants saw different portions of the recording due to trial randomization and trial length. The third pattern was a series of computer-generated concentric squares which were successively presented at 160-ms intervals from the smallest to the largest until the television screen was filled, and then successively erased from the screen. Pilot testing and a previous experiment (Richards, 1987) ensured that these three stimuli resulted in a first fixation duration of greater than 9 s for each of the three testing age groups. Each of the stimuli were presented within three-trial blocks, with the order within the block being random. The remainder of the procedure was identical to Experiment 1.

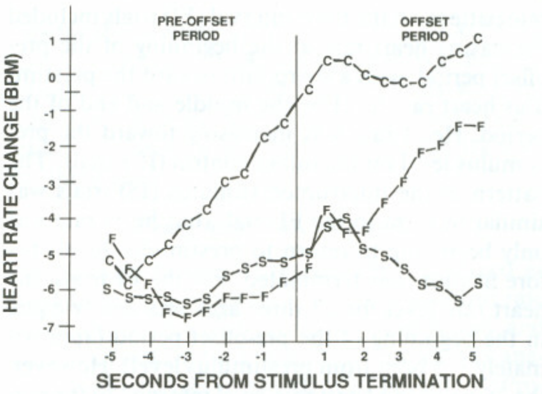


Figure 2. Average heart rate difference between the prestimulus and the pre-offset and offset periods for fixed interval (F), infant control (C), and interrupted stimulus (S) trials for Experiment 2.

Results

Fixation Duration

The duration of the primary stimulus was analyzed with an Age(3) × Extent of RSA(2) × Procedure(3) ANOVA. There were significant effects of age, $F(2/24)=5.51$, $p<.05$, and type of procedure, $F(2/48)=39.79$, $p<.001$. As in the first experiment, fixation duration was the longest on the infant control (IC) trials ($\overline{X}=14.29$ s), at an intermediate level on the interrupted stimulus (IS) trials ($\overline{X}=10.24$), and by definition, was 7 s on the fixed interval (FI) trials. On both IC and IS trials, the 14 week olds looked for the longest periods ($\overline{X}$'s = 17.53 and 12.17 s), the 20 week olds for an intermediate duration ($\overline{X}$'s = 12.5 and 10.2 s), and the 26 week olds for the shortest duration ($\overline{X}$'s = 12.8 and 8.3 s). The Procedure × Age interaction was not significant when only the IC and IS trials were included in the analysis.

Heart Rate Onset Response

The heart rate onset response was very similar to that found in Experiment 1, although it was slightly larger. There was a significant heart rate deceleration of about 6–7 bpm, which did not differ for age, procedure, or RSA groups.

Heart Rate Pre-offset Response

The heart rate response during the 5 s immediately preceding the termination of the stimulus was analyzed as the difference between the 0.5-s values and the 2.5-s prestimulus mean value. This difference was analyzed with an Age(3) × Extent of RSA(2) × Procedure(3) × Intervals(10) ANOVA. There was a significant effect of the intervals factor, $F(9/216)=4.95$, $p<.01$, and a Procedure × Intervals interaction, $F(18/432)=5.88$, $p<.01$. A simple main effects analysis for the three procedures showed significant intervals effects for all three procedures. *Post hoc* comparison tests revealed that the interrupted stimulus (IS) and fixed interval (FI) trials were not significantly different in the intervals factor, but that the infant control (IC) trials were different on the intervals factor from both the IS and FI trials (p's$<.01$). There were no significant effects involving age or extent of RSA. Figure 2 presents the heart rate difference from the prestimulus period for both the pre-offset and offset periods of Experiment 2.

Heart Rate Offset Response

The heart rate offset response was analyzed as it was in Experiment 1. The pattern of the response, as well as the significant effects, were nearly identical across the two experiments, and thus the analyses are not reported. As can be seen in Figure 2, both the infant control and fixed interval trials showed a brief and small heart rate deceleration following stimulus offset. Not shown, but parallel with the results of Experiment 1, the offset response of the high RSA group was larger than that of the low RSA infants, and accounted for most of the heart rate deceleration at offset found in Figure 2.

Discussion

The offset responses found in Experiment 2 were nearly identical to those found in Experiment 1. The age effect on the pre-offset heart rate pattern that was found in Experiment 1 on the fixed interval trials was not repeated in Experiment 2. The differential return to prestimulus level for the three ages in Experiment 1 was probably due to the duration of fixation. The average duration of uninterrupted fixation on the infant control trials in Experiment 1 ($\overline{X}$=7.6 s for 26 week olds) was nearly equal to the fixed interval trials, but was much longer in Experiment 2 ($\overline{X}$=12.6 s for 26 week olds). Thus, in Experiment 1, stimulus offset on the fixed interval trials occurred near the beginning of attention disengagement for the 26 week olds, but during attention engagement in Experiment 2. There was still, however, a brief slowing of heart rate on those trials at stimulus offset.

The size of the heart rate offset response found in Experiments 1 and 2 was smaller than had been previously reported. The difference between these studies may be the length of the stimulus and the events surrounding stimulus offset. For stimuli of long duration, attention to the stimulus may have ceased, whereas for stimuli of relatively short duration, attention may still be engaged. Experiment 3 will test the hypothesis that the attention status of the infant needs to be assessed to understand the heart rate offset response, and the hypothesis that physiological response to the visual stimulus must be completed before an offset response can occur. In Experiment 3, heart rate responses to the offset of stimuli of long (20 and 25 s) and short (7 s) duration will be studied. Using heart rate deceleration and acceleration as indices of the attention status, the heart rate response to stimulus offset occurring at maximal attention (heart rate deceleration) or after attention wanes (heart rate acceleration) will also be studied. A manipulation of Experiment 3 will be to compare offset responses to localized visual stimuli (on the TV screen) with responses to global visual stimuli (overall light change in room). Using visual stimuli on a TV screen is methodologically different from auditory stimuli because the visual stimuli are localized and offset responses must be studied during fixation, making trial lengths short and making the offset occur when the child may still be paying attention. The heart rate response at stimulus offset for the various conditions was also compared to a control trial on which all of the time criteria had been met, but the stimulus remained on.

EXPERIMENT 3

Methods

Subjects

The procedures for procuring and using subjects was identical to the previous experiments. The mean testing ages of the infants were 100.1 days (SD=5.70), 143.3 days (SD=3.39), and 187.8 days (SD=7.35), respectively. Twenty subjects at each testing age were used. Ten subjects at each age were presented with the TV stimuli before the overhead illumination, and 10 were presented with the stimuli in the opposite order. Twenty-six additional subjects did not maintain the required alert, awake state during the duration of the testing (approximately 35 min total time) and were not included in the analysis. Twenty-one of these subjects became fussy or irritable during the overall illumination trials, whereas only 5 became irritable during the TV presentations. Anecdotal observations suggested that the infants found the TV presentations interesting and exciting, and often vocalized or reached for the screen. However, they appeared to find the illumination change uninteresting, and often became restless and agitated, accounting for the higher attrition rate in that condition.

Apparatus and Procedure

The presentation apparatus was identical to that of Experiment 1. The three stimuli used in Experiment 2 were the stimuli shown on the TV. The overhead light was the illumination from a 60 watt light bulb placed approximately 3 ft above and behind the infant's head. The light, when illuminated, lighted the stimulus presentation area, and the shadow cast by the light was well below the normal viewing angle of the infant seated on the parent's lap. The procedure for presentation of the TV stimuli and overhead light was identical to that of the previous experiments. A 10-s period with the recording of data followed each trial. An intertrial interval which varied randomly from 0–2.5 s followed the trial, giving a total interstimulus interval of 12.5–15 s (10 s poststimulus, 0–2.5 s intertrial, minimum 2.5 s prestimulus).

The time of the stimulus offset was determined by one of six criteria: 1) *HRDEC:* offset when a significant heart rate deceleration had occurred, defined as five successive heartbeats with periods longer than the median period of the five heartbeats preceding the presentation of the visual stimulus; 2) *HRACC:* offset when heart rate began to return to prestimulus level following a heart rate deceleration, with acceleration defined as five successive heartbeats with periods shorter than the median period of the five prestimulus heartbeats; 3) *7SEC:* offset at 7 s following stimulus onset; 4) *IC:* offset when the infant looked away (TV stimuli only); 5) *20SEC:* offset at 20 s following stimulus onset (light only); and 6) a control trial for which offset occurred 5 s after all of the criteria had been met. The TV stimuli trials and the overhead light trials were each presented in random order within a block. The order of presentation of the blocks of trials was randomly determined, and half of the subjects at each age received each testing order.

Results

Stimulus Duration

Stimulus duration was analyzed from the five trial types that did not have fixed interval procedures. These were HRDEC and HRACC with the TV or with the overhead illumination, and infant control (IC) with the TV. The duration of the pri-

Table 1
Stimulus durations for Experiment 3 for the trials with varying durations

Trial Types	Mean Stimulus Durations (seconds) (SDs in Parentheses)
HRDEC, with TV	2.45 (1.47)
HRDEC, with light	3.28 (1.70)
HRDEC, with TV, control	3.37 (2.05)
HRDEC, with light, control	4.00 (3.02)
HRACC, with TV	12.6 (6.37)
HRACC, with light	11.5 (8.45)
HRACC, with TV, control	13.4 (9.90)
HRACC, with light, control	15.2 (11.3)
Infant Control, with TV	17.7 (10.9)
Infant Control, with TV, control	20.5 (8.50)

mary stimulus was analyzed with an Age(3) × Extent of RSA(2) × Testing Order(2) × Control(2) × Procedure(5) ANOVA. The only significant effect was for procedure, $F(4/192)=94.31$, $p<.001$. Table 1 shows the mean stimulus durations on these trials. *Post hoc* comparisons revealed that stimulus duration on the experimental trials and their appropriate controls were not significantly different for any of the procedures. However, the HRDEC, HRACC, and IC trial stimulus durations were all significantly different from each other (p's$<.05$).

Heart Rate Onset Response

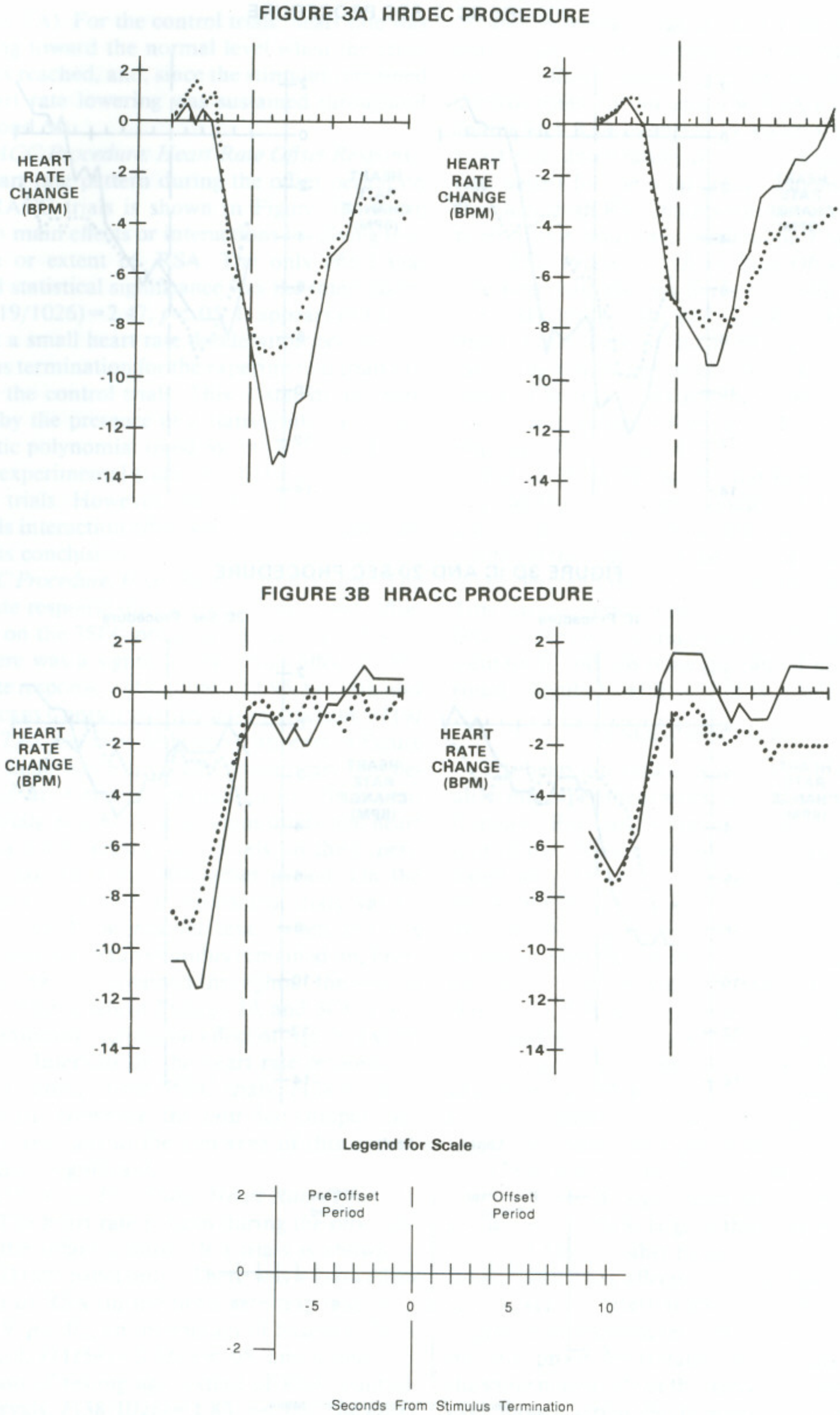
The heart rate onset response was analyzed as the difference in the 0.5-s values of heart rate during the first 5 s of trial duration and the 2.5-s prestimulus mean. This change was analyzed with an Age(3) × Extent of RSA(2) × Stimulus Type(2) × Procedure(5) × Intervals(10) ANOVA. There were no significant main effects or interactions involving age or extent of RSA. There were significant effects of intervals, $F(9/486)=118.46$, $p<.001$, and stimulus type, $F(1/54)=19.96$, $p<.001$, and a Type × Intervals interaction, $F(9/486)=90.20$, $p<.001$. Heart rate showed a significant deceleration of 9 bpm which was nearly identical in form to that reported in Richards (1985b) and Experiments 1 and 2. A simple main effects analysis showed that the response patterns were similar for the two stimulus types, but that the heart rate deceleration response was larger for the TV stimuli than for the overhead light.

Heart Rate Pre-Offset and Offset Responses

The pre-offset and offset heart rate responses were analyzed separately for each procedure. Each procedure (HRDEC, HRACC, 7SEC, IC, 20SEC) should result in very different pre-offset and offset heart rate patterns, and higher-order interactions would be difficult to interpret without the comparisons separated by each procedure. For each procedure's offset period, the difference in the 2.5-s prestimulus mean heart rate and the heart rate values during the 5 s following the termination of the stimulus was analyzed with an Age(3) × Extent of RSA(2) × Control(2) × Stimulus Type(2) × Intervals(20) ANOVA. Figure 3 (in two parts) shows the pre-offset and offset responses from 5 s preceding stimulus termination through 10 s following stimulus termination. Each figure has the relevant portion of the control trial superimposed on the heart rate data from the experimental trial.

Heart Rate Pre-Offset Response. The 5 s preceding the point of stimulus termination was analyzed separately for the procedures (HRDEC, HRACC, 7SEC, IC, and 20SEC) with an Age(3) × Extent of RSA(2) × Control(2) × Intervals(10) ANOVA. The HRDEC, HRACC, and 7SEC procedures were presented for both stimulus types, and also included a Stimulus Type(2) factor in their ANOVAs. The results of the analysis will only be summarized. First, there were no main effects or interactions involving testing age or extent of RSA for any of the procedures. Second, there were no main effects or interactions involving the control factor. Third, there was a significant effect of the intervals factor on all procedures except the 20SEC trials. Heart rate was decelerating on the HRDEC trials (Figure 3A), accelerating toward the prestimulus level on the HRACC (Figure 3B) and IC (Figure 3D, left panel) trials, was stable on the 20SEC trials (Figure 3D, right panel), and was finishing up the heart rate onset deceleration response on the 7SEC trials (Figure 3C). Finally, the HRDEC and HRACC trials had significant main effects of stimulus type, and Stimulus type × Intervals interaction effects. These effects were similar in nature to the onset heart rate response, and were due to the larger heart rate deceleration response to the TV stimuli.

HRDEC Procedure: Heart Rate Offset Response. Figure 3A shows the heart rate response occurring on the HRDEC procedure. There were no main effects or interactions involving testing age or extent of RSA. There was a main effect on the heart rate response of intervals, $F(19/1026)=52.54$, $p<.001$, and interaction effects of Control × Intervals, $F(19/1026)=7.46$, $p<.001$, and Stimulus type × Intervals, $F(19/1026)=2.89$, $p<.05$. *Post hoc* comparisons were used to further examine the Control × Intervals interaction effect. For the experimental trials, heart rate continued to decelerate by 2–5 bpm during the first 5 s following stimulus offset, and then returned to prestimulus level in the second 5



Figures 3A and 3B. Average heart rate difference between the prestimulus and the pre-offset and offset periods for the experimental (solid line) and control (dotted line) trials, plotted separately for the HRDEC and HRACC procedures of Experiment 3. The left hand panels are for the trials with TV stimuli, and the right hand panels are for trials with the overhead light.

FIGURE 3C 7 SEC PROCEDURE

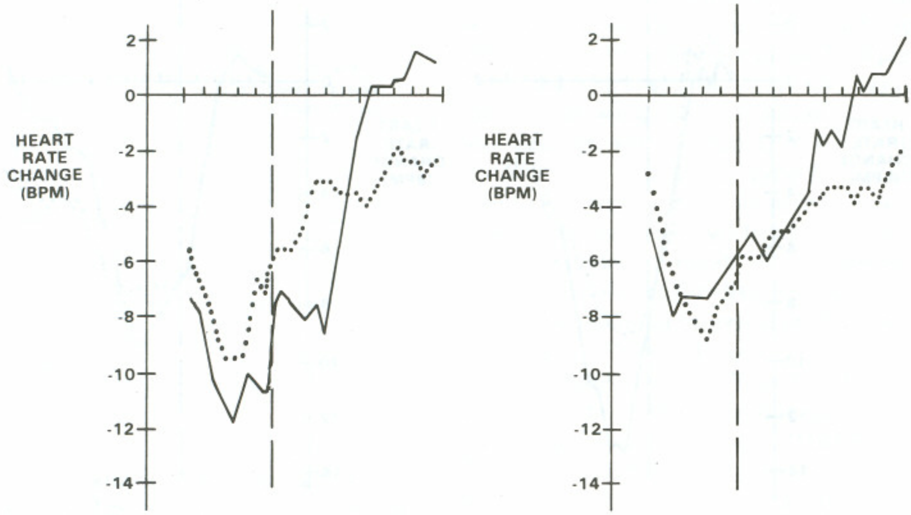
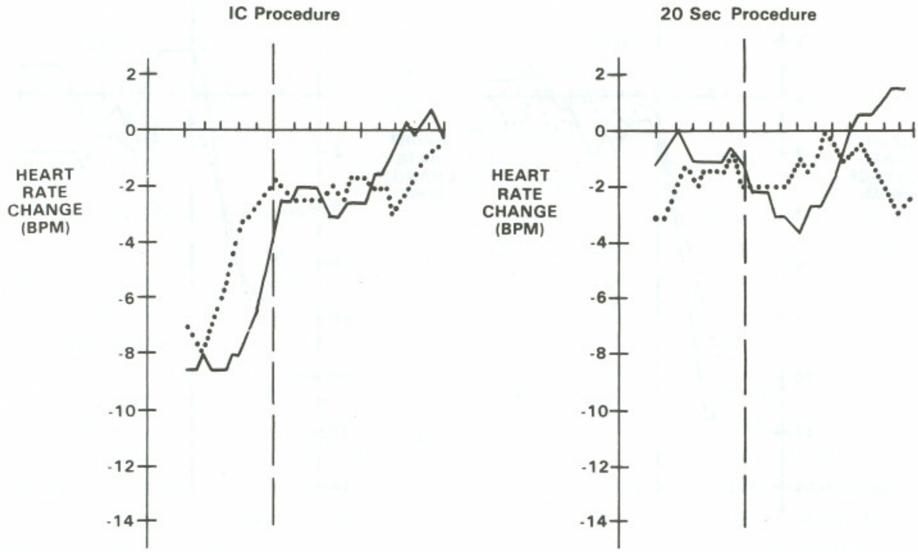
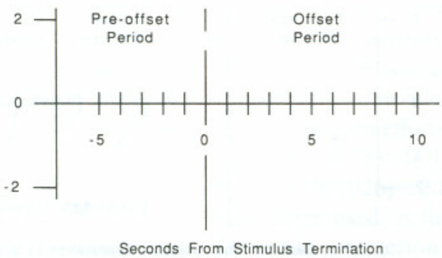


FIGURE 3D IC AND 20 SEC PROCEDURE



Legend for Scale



Figures 3C and 3D. Average heart rate difference between the prestimulus and the pre-offset and offset periods for the experimental (solid line) and control (dotted line) trials, plotted separately for the 7SEC, infant control (IC), and 20SEC procedures of Experiment 3. The left hand panels are for the trials with TV stimuli, and the right hand panels are for trials with the overhead light.

s (Figure 3A). For the control trials, heart rate was returning toward the normal level when the criterion was reached, and, since the stimulus remained on, heart rate lowering was sustained throughout the second 5 s.

HRACC Procedure: Heart Rate Offset Response. The heart rate pattern during the offset period on the HRACC trials is shown in Figure 3B. There were no main effects or interactions involving testing age or extent of RSA. The only effect that reached statistical significance was the intervals effect, $F(19/1026)=2.47$, $p<.05$. It appears in Figure 3B that a small heart rate deceleration occurred at stimulus termination for the experimental trials but not for the control trials. This is statistically supported by the presence of a statistically significant quadratic polynomial trend for the intervals factor on the experimental trials ($p<.01$) but not on the control trials. However, the omnibus Control × Intervals interaction effect was not significant, limiting this conclusion.

7SEC Procedure: Heart Rate Offset Response. The heart rate response during the pre-offset and offset periods on the 7SEC procedure is shown in Figure 3C. There was a significant intervals effect on the heart rate response, $F(19/1026)=23.95$, $p<.001$, and a significant Control × Intervals interaction, $F(19/1026)=7.47$, $p<.001$. Although it appears in Figure 3C that there was a brief and small heart rate deceleration at stimulus termination for the experimental trials, *post hoc* comparisons imply that heart rate returned to prestimulus levels on the experimental trials over the 10-s offset period. On the other hand, heart rate in the control trials was returning toward the normal level when the 7 s elapsed, and, since the stimulus remained on, heart rate lowering was sustained throughout the second 5 s (cf. control trials in Figures 5A and 5C). There was a significant interaction effect of Age × Extent of RSA × Intervals on the heart rate response in the offset period of the 7SEC trials, $F(38/1026)=1.64$, $p<.01$. However, the *post hoc* comparisons that were relevant to the concerns of this experiment were insignificant.

Infant Control Procedure: Heart Rate Offset Response. The heart rate pattern during the offset period of the infant control (IC) trials is shown in Figure 3D (left panel only). There was a main effect of extent of RSA on the heart rate response, $F(1/54)=4.19$, $p<.05$, an interaction of Extent of RSA × Control, $F(1/54)=5.38$, $p<.05$, and a four-way interaction of testing age, extent of RSA, control, and intervals, $F(38/1026)=1.83$, $p<.05$. The effect most relevant to the concerns of the experiment is the four-way interaction. The pattern of *post hoc* comparisons showed that the high RSA infants at 20 and 26 weeks of age showed a heart rate deceleration at stimulus termination on the IC trials. Similar offset responses did not occur (a) on the control trials, (b) for any low RSA groups, or (c) for the high RSA infants at 14 weeks of age. A small heart rate deceleration can be seen in Figure 3D (left panel) for the total group response, and it is the older, high RSA infants who are accounting for most of this heart rate deceleration response.

20SEC Procedure: Heart Rate Offset Response. The heart rate pattern during the offset period of the 20SEC trials is shown in Figure 3D (right panel only). There were no main effects or interactions involving testing age or extent of RSA. The main effect of intervals was not statistically significant, but the interaction of Control × Intervals was significant, $F(19/1026)=4.26$, $p<.01$. It can be seen in Figure 3D (right panel) that there was a heart rate deceleration (approximately 4 bpm) on the 20SEC experimental trial, whereas heart rate was stable for the first 5 s of the control trial and began to decelerate in the second 5 s of this offset period. This late deceleration in the control trial is of note, because the control trial was actually a trial of 25-s duration, and this represents an offset response of equal magnitude with the 20SEC trial.

GENERAL DISCUSSION

The heart rate offset response to the visual stimuli in this experiment was small relative to the onset response. For most of the procedures, the magnitude of the response was about 1.5 to 2 bpm, compared with the onset heart rate deceleration magnitude of 6 (Experiments 1 and 2) or 9 (Experiment 3) bpm. The largest offset response occurred in Experiment 3 for the 20SEC procedure trials (4 bpm), and in the HRDEC trials of that same experiment (Figure 3A, left panel). The magnitude of the heart rate offset response in the fixed interval procedures may be partially related to the duration of the stimulus. The 7-s trials showed heart rate offset response levels comparable to those of Berg (1972, 1974), using 10-s trials. The experimental (20 s) and control (25 s) trials of the 20SEC procedure of Experiment 3 showed larger heart rate offset responses, though not nearly as large as those reported by Lewis (1971). On the other hand, it is not stimulus duration alone that affects the magnitude of the response. The shortest trials in this study had the largest offset response (HRDEC trials). The subject-initiated procedure (infant control trials) produced the same magnitude of the heart rate offset response even though across the three experiments there was an increasing duration of the stimulus for this procedure (10, 14, and 17 s, for Experiment 1, 2, and 3, respectively). It is clear that no matter what the important variable, the heart rate offset response of the infant is much smaller than the orienting response.

Several findings in the present study extend the use of the offset response to the study of subject-controlled attention. The initial heart rate deceleration response was followed by a sustained lowering of heart rate as long as the stimulus remained on, and the infant was looking and interested (e.g., control trials of HRDEC and 7SEC procedures of Experiment 3). Immediately before looking away on the infant control (IC) trials, heart rate began to return to prestimulus levels. This pattern held over the three studies, even though these trials were determined by the fixation of the subject, which was of markedly differing durations on the IC trials for the three experiments. In contrast to the IC trials, for the interrupted stimulus (IS) trials the pre-offset heart rate was only beginning to return to its prestimulus level when the infant turned toward the interrupting stimulus. This suggests that fixation termination on these trials occurred coincident with the beginning of active attention termination, whereas on the IC trials, active attention had totally ceased (perhaps for some time) before fixation was terminated. The pattern of the pre-offset heart rate response on the IC trials was identical to that occurring on the HRACC trials in Experiment 3. This similarity is significant because it has been shown that infants are more easily distracted after the heart rate response is finished (e.g., HRACC procedure), indicating that sustained attention has ended (Richards, 1987). Thus, heart rate lowering is sustained as long as the infant is looking and interested, and the infant is distractible by an interrupting stimulus at the point at which heart rate begins to return to prestimulus levels (HRDEC trials). When heart rate returns to prestimulus levels, the probability of the infant voluntarily looking away (IC trials) or being distracted by another stimulus (HRACC trials) increases. The *physiological* signs which indicate that sustained attention is occurring covary closely with *behavioral* markers of sustained attention (cf. Richards, 1987, 1988).

A second finding which applies to the study of subject-controlled attention processes is the similarity between the heart rate offset response across conceptually differing procedures. Conceptually, the IC trials represent subject-initiated stimulus termination, the HRACC trials (Experiment 3) represent the waning of sustained attention, and the 7SEC trials represent experimenter-initiated stimulus termination. However, the offset for each of these procedures was a small magnitude heart rate deceleration of brief duration. A common phenomenon for these procedures was that stimulus offset occurred at the accelerating portion of the heart rate response. On the other hand, a stable heart rate level was found in the pre-offset period of the 20SEC procedure in Experiment 3, and a large offset response relative to the other procedures. It may be that the heart rate attention response must be completely finished before the full heart rate offset response can be elicited.

A most unusual finding in Experiment 3 was the magnification of the heart rate orienting response by the preemptive termination of the stimulus on the HRDEC trials. On the control trials for both the TV stimuli and the overhead light the heart rate response was a deceleration, slight return toward prestimulus levels, and a sustained heart rate lowering over the 10 s following the HRDEC criterion (Figure 3A). On the other hand, when the stimulus was terminated at the HRDEC criterion, there was an additional 2 (overhead light) to 4 (TV stimuli) bpm decrease in heart rate larger than the control trials. It appears as if the infant was beginning to actively process the information in the visual stimulus, and was surprised by the termination, responding with a further heart rate deceleration. This finding points to the necessity of evaluating the infant's attention status when doing experimental manipulations.

High RSA infants responded with larger heart rate offset responses in all three experiments, replicating previous research. Porges and his associates have reported that newborns with little heart rate variability show smaller, or no, offset response to auditory and visual stimuli (Porges et al., 1973, 1974). On the other hand, newborns with high heart rate variability show a heart rate deceleration to an auditory stimulus offset (Porges et al., 1973). The offset response to an illumination change was reported to be an acceleration of heart rate on the initial trials, which progressively became deceleratory with repeated stimulus presentation (Porges et al., 1974). It was thought in the present study that the subject-controlled procedures for stimulus termination might be differentiated by the level of RSA, since RSA level indexes subject-controlled, sustained attention in infants (Richards, 1985b, 1987). Although infants with more heart rate variability (high extent of RSA) showed larger heart rate offset responses than those with low levels of heart rate variability, this was true for both experimenter-initiated (7SEC trials, Experiments 1 and 2) and subject-initiated (IC trials, all three experiments) stimulus termination. RSA level may be indexing some level of the building up of expectancies about stimulus occurrence, and responsiveness to the violation of that by stimulus termination. It is not merely heart rate responsiveness that is indexed by RSA level, since the level of the heart rate orienting response occurring at stimulus onset was not differentiated by level of RSA in these experiments, nor in previous ones (Richards, 1985b, 1987). Rather, the relation of RSA to the heart rate offset response is particular to some type of attention process occurring near the termination of visual attention.

The interpretation of the heart rate offset response in the Sokolovian model is weak. The heart rate offset response is not as large as the heart rate orienting response occurring at stimulus onset, and, according to most reports, fails to habituate with repeated stimulus presentation. It is also differentiated by the level of RSA, whereas the orienting response is not. The heart rate offset response is affected by several experimental and organismic variables. It is very large when the infant appears to be settling in for a period of attention, small if given at intermediate periods of time (7 s, 10 s), small if attention to the stimulus has waned (HRACC trials), and once again becomes large when the stimulus is terminated after a relatively long period of time (20 s). It is affected by subject-initiated looking away (IC trials), and is larger in infants with large amounts of RSA, especially the older ones. In the perspective of the present study the heart rate offset response is a useful index of the status of current information processing of the infant. However, it is not easily fit into the traditional Sokolovian model of psychophysiological responsiveness.

REFERENCES

Adkinson, C.D., & Berg, W.K. 1976. Cardiac deceleration in newborns: Habituation, dishabituation, and offset responses. *Psychophysiology, 21*, 46–60.

Berg, W.K. (1972). Habituation and dishabituation of cardiac responses in 4-month-old, alert infants. *Journal of Experimental Child Psychology, 14*, 92–107.

Berg, W.K. (1974). Cardiac orienting responses of 6- and 16-week-old infants. *Journal of Experimental Child Psychology, 17*, 303–312.

Bloomfield, P. (1976) *Fourier analysis of time-series: An introduction.* New York: Wiley.

Brooks, P.R., & Berg, W.K. (1979). Do 16-week-old infants anticipate stimulus offsets? *Developmental Psychobiology, 12*, 329–334.

Cohen, L.B. (1972). Attention-getting and attention-holding processes of infant visual preferences. *Child Development, 43*, 869–879.

Greenhouse, S.W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*, 95–112.

Graham, F.K. (1973). Habituation and dishabituation of responses innervated by the autonomic nervous system. In H.V.S. Peeke & M.J. Herz (Eds.), *Habituation: Behavioral studies and physiological substrates* (pp. 163–218). New York: Academic Press.

Graham, F.K. (1978). Constraints on measuring heart rate and period sequentially through real and cardiac time. *Psychophysiology, 15*, 492–495.

Graham, F.K. (1979). Distinguishing among orienting, defensive, and startle reflexes. In H.D. Kimmel, E.H. van Olst, & J.F. Orlebeke (Eds.), *The orienting response in humans* (pp 137–167). Hillsdale, NJ: Erlbaum.

Graham, F.K., & Clifton, R.K. (1966). Heart-rate change as a component of the orienting response. *Psychological Bulletin, 65*, 305–320.

Harper, R.M., Walter, D.O., Leake, B., Hoffman, H.J., Sieck, G.C., Sterman, M.B., Hoppenbrouwers, T., & Hodgman, J. (1978). Development of sinus arrhythmia during sleeping and waking states in normal infants. *Sleep, 1*, 33–48.

Horowitz, F.D., Paden, L., Bhana, K., & Self, P. (1972). An infant-control procedure for studying infant visual fixations. *Developmental Psychology, 7*, 90.

Karmel, B.Z., & Maisel, E.G. (1975). A neuronal activity model for infant visual attention. In L.B. Cohen & P. Salapatek (Eds.), *Infant perception: From sensation to cognition* (Vol. 1, pp. 77–131). New York: Academic Press.

Lewis, M. (1971). A developmental study of the cardiac response to stimulus onset and offset during the first year of life. *Psychophysiology, 8*, 689–698.

Porges, S.W. (1976). Peripheral and neurochemical parallels of psychopathology: A psychophysiological model relating autonomic imbalance in hyperactivity, psychopathology, and autism. In H. Reese (Ed.), *Advances in child development and behavior* (Vol. 11, pp. 35–65). New York: Academic Press.

Porges, S.W. (1980). Individual differences in attention: A possible physiological substrate. In B.K. Keogh (Ed.), *Advances in special education* (Vol. 2, pp. 111–134). Greenwich, CT: JAI Press.

Porges, S.W., Arnold, W.R., & Forbes, E.J. (1973). Heart rate variability: An index of attention responsiveness in human newborns. *Developmental Psychology, 8*, 85–92.

Porges, S.W., McCabe, P.M., & Yongue, B.G. (1982). Respiratory-heart rate interactions: Psychophysiological implications for pathophysiology and behavior. In J. Cacioppo & R. Petty (Eds.), *Perspectives in cardiovascular psychophysiology* (pp. 223–264). New York: Guilford Press.

Porges, S.W., Stamps, L.E., & Walter, G.F. (1974). Heart rate variability and newborn heart rate responses to illumination changes. *Developmental Psychology, 10*, 507–513.

Richards, J.E. (1980). The statistical analysis of heart rate: A review emphasizing infancy data. *Psychophysiology, 17*, 153–166.

Richards, J.E. (1985a). Respiratory sinus arrhythmia predicts heart rate and visual responses during visual attention in 14 and 20 week old infants. *Psychophysiology, 22*, 101–109.

Richards, J.E. (1985b). The development of sustained visual attention in infants from 14 to 26 weeks of age. *Psychophysiology, 22*, 409–416.

Richards, J.E. (1987). Infant visual sustained attention and respiratory sinus arrhythmia. *Child Development, 58*, 488–496.

Richards, J.E. (1988). Heart rate responses and heart rate rhythms, and infant visual sustained attention. In P.K. Ackles, J.R. Jennings, & M.G.H. Coles (Eds.), *Advances in psychophysiology* (Vol. 3, pp. 189–221). Greenwich, CT: JAI Press.

Sokolov, E.N. (1963). *Perception and the conditioned reflex.* New York: Macmillan.

(Manuscript received July 11, 1986; accepted for publication November 18, 1987)