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Heart Rate and Behavioral Measures of Attention in Six-, Nine-, and Twelve-Month-Old Infants during Object Exploration

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In this study we examined the effect of heart rate and behavioral measures of attention on distractibility of 6-, 9-, and 12-month-old infants. The infants were presented with a toy, and a distractor was presented while they attended to the toy. The distractor was presented during heart rate changes indicating sustained attention or attention termination, or during periods of time when behavioral ratings indicated the infant was in focused or casual attention. There were longer distraction latencies during attentional engagement as defined by heart rate changes or behavioral ratings than for periods of inattention. Infants had the longest distraction latencies when heart rate and behavior measures were congruent with respect to attention engagement (heart rate deceleration and focused attention). Conversely, latencies were shortest for congruent values of inattention (heart rate acceleration and casual attention). Infant information processing may be greatest when a heart rate deceleration occurs simultaneously with an episode of focused attention.

INTRODUCTION

Multiple phases of attention have been hypothesized to occur during visual fixation in infants. Research using behavioral measures of attention engagement refer to these as focused attention and casual attention. Oakes, Madole, and Cohen (1991) found differences in active processing of stimulus information between periods of time when infants were examining objects or toys and periods of time when infants were casually attending to them. Research employing heart rate as an index of attention also has distinguished separable attention phases (Casey & Richards, 1988; Richards & Casey, 1991). These phases include stimulus orienting, sustained attention, and attention termination. Information is processed differentially across these phases (Richards, in press–a). In this study we examined the relation between heart rate and behavioral measures of attention while infants engaged in exploration of objects. The heart-rate-defined sustained attention and attention termination were compared with behavior-defined focused and casual attention, respectively.

Research using behavioral ratings of attentive and inattentive fixation has shown that infants' engagement differs during a single fixation episode. Examining (attentive fixation) may be loosely defined as "looking, usually, some combination of fingering and turning the object around, and an intent expression on the face" (Ruff, 1986). Nonexamining (inattentive fixation), on the other hand, does not contain periods of concentration and inspection. Periods of active examining represent "focused attention" to the objects, whereas nonexamining periods are "casual attention." Infant distractibility has been studied as a function of focused and casual attention. Infants take longer to look from an object to a distracting stimulus when they are engaged in active examination of the object (Oakes & Tellinghuisen, 1994; Ruff, Capozzoli, & Saltarelli, in press; Tellinghuisen & Oakes, in press). It should be noted that focused attention and casual attention, as they are defined here, are mutually exclusive; if an infant is looking at a toy, the fixation must be judged as focused *or* casual attention. Focused and casual attention represent behaviorally defined periods of "attentive" and "inattentive" activity, respectively.

Heart rate changes also have been used to distinguish levels of attention engagement during a single look. Stimulus orienting is identified as an initial deceleration in heart rate at the onset of the stimulus. Sustained attention immediately follows stimulus orienting and is accompanied by a sustained lowered heart rate. Heart rate returns to prestimulus level during attention termination. Attention phase (sustained attention, attention termination) has been shown to be related to distraction latency in a manner similar to behavioral ratings of attention in that infants took longer to look at a distractor when it was presented during sustained attention than during attention termination (Casey & Richards, 1988; Richards, 1987, in press–b). Sustained attention and attention termination represent heart-rate-defined periods of "attentive" and "inattentive" activity, respectively.

Table 1 Heart Rate and Behavioral Definitions of Attentive and Inattentive Object Exploration

Attentive object exploration: Information processing; intensity and selectivity	
	Sustained attention: Heart-rate-defined; deceleration; heart rate slower than prestimulus rate (e.g., Casey & Richards, 1988)
	Focused attention: Behaviorally defined; object-directed behavior; intent facial expression, object manipulation (e.g., Ruff, 1986)
Inattentive object exploration: No information processing; inactive state; "default" state	
	Attention termination: Heart-rate-defined; heart rate returns to prestimulus level after deceleration (e.g., Casey & Richards, 1988)
	Casual attention: Behaviorally defined; object-directed behavior not coded as focused attention (e.g., Ruff, 1986)

The research using heart rate as a measure of attention, and that using behavior as a measure of attention, posit similar characteristics of the levels of attention engagement. Sustained attention and focused attention presumably represent periods of active information processing. For example, infants' memory for a stimulus was better when that stimulus was presented during a period of heart rate deceleration (sustained attention) than when heart rate had returned to its prestimulus level (attention termination) (Richards, in press–a). The duration and frequency of behavior-defined focused attention has been found to decrease during repeated stimulus presentations, whereas the duration and frequency of casual attention did not vary over this period (Oakes et al., 1991; Ruff, 1986; Ruff, Saltarelli, Capozzoli, & Dubiner, 1992). Distraction latency to a peripheral stimulus takes longer in heart-rate-defined sustained attention (Richards, 1987) or behaviorally defined focused attention (Oakes & Tellinghuisen, 1994; Ruff et al., in press) than during attention termination or casual attention. Table 1 illustrates the similarities between heart rate and behavioral ratings of attention. The heart rate and behavioral ratings of attention level have not been compared directly. The main goal of this study was to examine the relation between heart rate and behavioral measures of attention.

The latency to localize a peripheral stimulus while fixated on a central stimulus (distraction latency) has been used in studies employing heart rate as an index of attention engagement as well as in studies where behavior was used as an index. Oakes and Tellinghuisen (1994) used computer generated stimuli to distract infants from a toy fastened to a high chair tray. They found that infants were less distractible while examining the toy than while engaged in nonexamining fixation. Ruff et al. (in press) found similar results by presenting slides for brief periods at random intervals while 10-month-old infants manipulated four toys. The latency to make a head turn was significantly longer for infants judged to be engaged in focused attention. The longer distraction latencies for the examining periods indicate that attention was focused on the object, whereas the shorter durations during nonexamining fixation represent casual attention. Distraction latency has been used in research where heart rate was used as an index of attention as well. Several studies have used an "interrupting stimulus" method in which infants of 14, 20, and 26 weeks of age were presented with varying and complex patterns on a TV screen (Casey & Richards, 1988; Richards, 1987, in press–b). A peripheral stimulus was presented at some delay after onset of fixation to the central stimulus. The delays were determined by changes in heart rate elicited by the central stimulus presentation. Infants took longer to look to the peripheral stimulus when heart rate deceleration had occurred than when heart rate had returned to its prestimulus level following a deceleration. Heart rate deceleration was taken as a sign of sustained attention to the stimulus, and distraction latencies were longer because the infant was directing processing to the central stimulus. The return of heart rate to its prestimulus level indicated that sustained attention was finished, even though the infant continued to look in the direction of the stimulus. The shorter distraction latencies in this latter case indicate that the infant is no longer engaged in attention to the central stimulus, that is, "attention termination" (Casey & Richards, 1988, 1991; Richards & Casey, 1991).

The major aim of this study was to establish a link between heart rate and behavioral ratings of infant visual attention using latency to look at a distractor as the dependent variable. The similarity in the distraction latencies between focused attention rated behaviorally, and sustained attention using heart rate deceleration, suggests that these may be measuring attention engagement. Alternatively, casual attention rated behaviorally and attention termination indicated by the return of heart rate to its prestimulus level measure a lack of attention engagement. In this study, infants from 6 to 12 months of age were presented with a small toy for exploration. After some delay, a distractor was presented to attract the infant's fixation away from the toy. The presentation of the distractor was contingent upon heart rate to differentiate sustained attention from attention termination, or behavioral ratings to distinguish focused attention from casual attention. Heart-rate-defined sustained attention and behaviorally defined focused attention should result in similar distraction latencies. These two conditions should produce distraction latencies that are significantly longer than when the distractor is presented contingent on attention termination (heart rate) or casual attention (behavioral rating).

The participants for this study were 6-, 9-, and 12-month-old infants. These ages were chosen for two reasons. First, infants from this age range have been used extensively in behavioral studies of focused and casual attention (Oakes & Tellinghuisen, 1994; Oakes et al., 1991; Ruff, 1986; Ruff & Lawson, 1990; Ruff et al., in press). Second, Richards and colleagues have shown heart rate to be an effective index of attention phases in infants from 3.5 to 6 months of age (Casey & Richards, 1988, 1991; Richards, 1987, 1994, in press–b). The age range in this study would test the extension of heart-rate-defined phases of attention to older infants and a new stimulus situation.

METHOD

Participants

Infants were recruited from birth notices published in a Columbia, SC newspaper. The infants were term, defined as having birthweight greater than 2,500 g and gestational age of 38 weeks or greater based on the mother's report of her last menstrual cycle. A cross-sectional design was used to sample 56 infants at ages 6 (n = 20, M = 184.6 days, SD = 3.75, 12 male, 8 female), 9 (n = 16, M = 275.3 days, SD = 5.22, 4 male, 12 female), and 12 (n = 20, M = 365.9 days, SD = 7.66, 11 male, 9 female) months postnatal age. A subset of this group was used to insure equal sample size and a balanced factorial design, and infants were selected who completed at least one successful trial in each trial type: 6 months (n = 11, M = 186.5 days, SD = 3.56, 6 male, 5 female), 9 months (n = 11, M = 275.3 days, SD = 5.29, 1 male, 10 female), and 12 months (n = 11, M = 368.3 days, SD = 6.00, 6 male, 5 female). Data from this subset were used in the analysis of the a priori experimental manipulations, whereas other analyses included all participants. There were four infants excluded from all analyses due to fussiness, and five infants' data were lost due to experimenter error. The infants had no acute or chronic pre- or perinatal medical complications and were in good health at the time of recording.

Apparatus and Stimuli

The infant and parent were seated next to a table with the infant seated in its parent's lap. A 49 cm TV monitor was located to the right of the infant at an angle of approximately 45°. One experimenter was seated adjacent to the table to the left of the infant. A video camera was located directly across the table from the infant. A monitor located in an adjacent room was used by a second experimenter to judge infant fixations on a toy. The session was recorded on a videotape with a time code to synchronize physiological and experimental information for analysis.

The stimuli consisted of six different toys that varied in color combinations as well as number of movable parts. Each toy could be secured to the table via suction cups connected to the bottom of the toy. This prevented the toys from being removed and thrown by the infant. Distractors for this experiment were all dynamic computer-generated patterns (e.g., a series of computer-generated concentric squares of varying size, a flashing checkerboard pattern, a small box shape moving in a diamond) presented on the TV monitor adjacent to the infant.

Procedure

The parent and infant were positioned so the infant could play comfortably with objects on the table. The experimenter began the experiment by securing one of the six toys to the table, the order of which was randomly assigned for each infant. Figure 1 shows the timeline of events occurring for each trial. The toy was blocked from the infant's view by a barrier that the experimenter held in front of the toy. The removal of the barrier signaled the beginning of the trial. The distractor was presented at some time after the infant began to explore the toy. After the infant had localized the distractor within each trial, the distractor was turned off and the barrier was replaced 5 s later, signaling the end of the trial. If the infant failed to look at the distractor within 30 s, the distractor was removed. The barrier was then replaced in front of the toy. Similarly, if the infant failed to exhibit the appropriate physiological or behavioral change for the distractor to be presented, that trial was repeated. The parent was instructed not to bounce or move the infant, but the infant's movements were not restrained.

The participants received two blocks of six trials. These trials included: (1) heart rate deceleration, (2) heart rate acceleration, (3) focused attention, (4) casual attention, (5) heart rate control, and (6) behav-

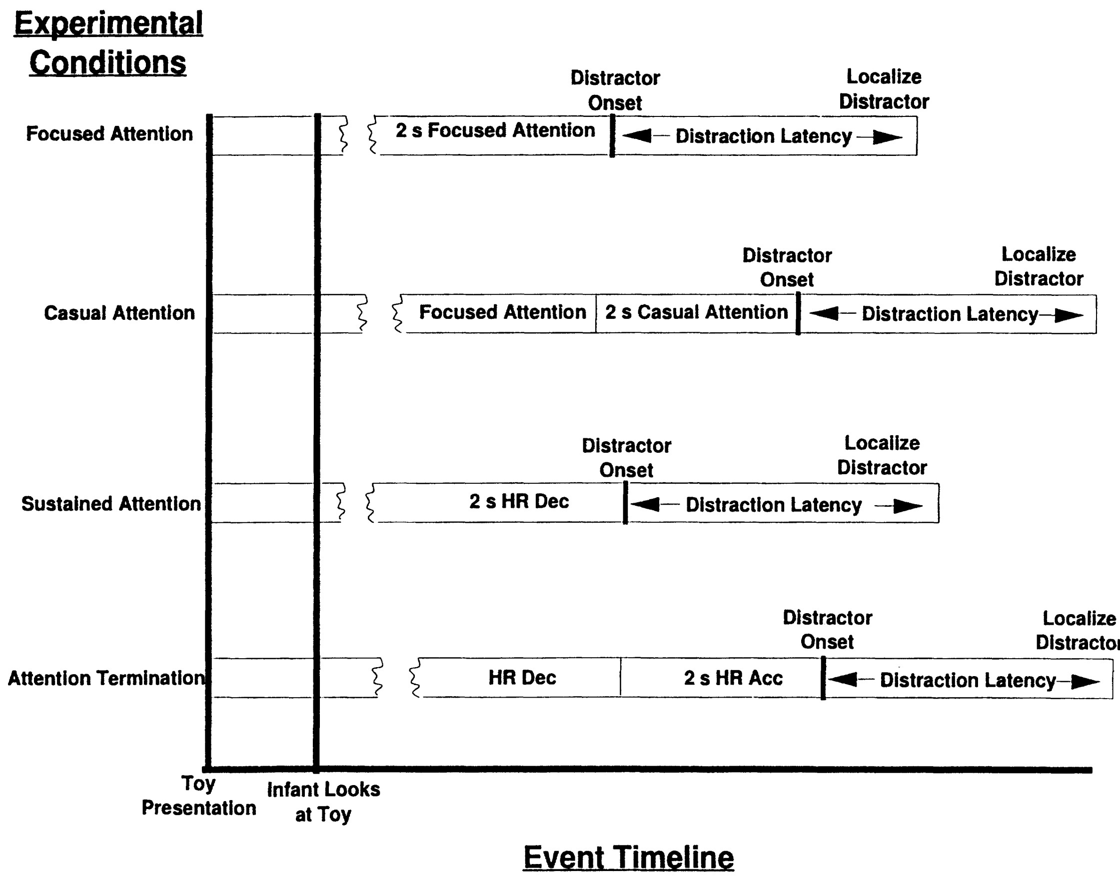

Figure 1 Schematic of events occurring during experimental trials. The broken line occurring before each trial type indicates an indefinite time occurring before the criteria were met for those trials.

ioral control (Figure 1). A heart rate deceleration was defined as five successive beats with heart period longer than the median period of the five heartbeats preceding the removal of the barrier. Heart rate acceleration was defined as five successive beats with heart period shorter than the median period of the five prestimulus heartbeats, and must have followed a deceleration. Focused attention was defined as periods in which the infant was judged to be looking at the toy, with some combination of fingering and turning the object around, and an intent expression on the face. Casual attention was defined as an episode in which the infant was judged to be looking at the object while not showing any of the focused attention criteria, and must have followed a period of focused attention. The distractor was presented after the infant had met the criteria for 2 s to eliminate transient changes in either the behaviorally defined or heart-rate-defined attention level (Figure 1). It should be noted that the presentation of the distractor in this study was contingent on the on-line behavioral ratings. This type of distractor contingency has been done in studies where heart rate was used as an index of attention but not in research utilizing behavioral measures. Each trial block also included heart rate and behavioral control trials. A heart rate control trial was identical to a heart rate acceleration trial except that there was no distractor presentation. Behavioral control trials were identical to casual attention trials except there was no distractor presentation. Participants were presented with as many of these six-trial blocks as possible before they became fussy. Procedure order was randomly chosen within each six-trial block.

The heart rate changes for the heart rate deceleration and heart rate acceleration were assessed from on-line recording of the electrocardiogram. The electrocardiogram was recorded with Ag-AgCl electrodes placed on the infant's chest using disposable electrode collars. The electrocardiogram was digitized at 1,000 Hz (each ms). The R-wave was identified in the electrocardiogram, and the interbeat inter-

Table 2 Percentage Agreement and Sample Size by Trial Type

	Trial Type					
	Heart Rate Deceleration	Heart Rate Acceleration	Focused Attention	Casual Attention	Heart Rate Control	Behavioral Control
%	71.1	75.6	95.8	95.6	79.0	91.9
N	142	140	144	140	143	137

val was defined as the duration between successive R-waves in the electrocardiogram. The interbeat intervals were identified on-line by a computer program so that evaluation of the heart rate changes could be made as soon as the heartbeat occurred.

Fixation Judgments

Each session was judged off-line by two observers, and data for the analysis came from one observer's judgments. A time code was recorded on the videotapes that allowed the judgments to have millisecond accuracy, although resolution was limited to a single video scan (0.5 * total frame length = ~16 ms). The time code on the videotape was synchronized with the computer clock to synchronize heart rate changes with fixation. The observers judged the infant as being in focused attention, casual attention, or as looking away. The two raters assessed the behavioral attention level on the behaviorally defined trials with consensus agreement. For the behaviorally defined conditions, only trials on which the coders agreed were used in analyses.

The agreement between the two observers for the fixation judgments was assessed for all infants (N = 56). The concordance between the two observers was assessed in two ways. First, the percentage of trials in which there was agreement between two coders of behavior at the distractor onset was determined. Table 2 contains these percentages as well as the total number of trials with which they were calculated. The percentages for focused attention, casual attention, and behavioral control trials were high because agreements were reached by consensus of the raters. Second, correlations were computed between the two raters' judgments of focused attention duration and casual attention duration for the heart rate and behavioral control trials. The two raters were blind as to the heart rate data. The correlations for judgments of focused attention duration were .82 and .88 for heart rate control and behavioral control trials, respectively. The corresponding correlations for casual attention judgments were .87 and .94.

RESULTS

Distraction Latencies

The a priori experimental manipulations were examined to determine if the presentation of the distractor contingent on heart-rate-defined attention and behaviorally defined attention affected the latency to look toward the distractor. Log transformations of the latencies were used in all analyses to reduce skewness in the dependent measure. The log-transformed latency was analyzed with an age (3) × attentive state (2; heart rate deceleration and focused attention combined, heart rate acceleration and casual attention combined) × measurement type (2; heart rate, behavioral) ANOVA.[1] The interaction between measurement type and age was significant, $F(2, 30) = 3.40$, $p = .047$. The 6- and 12-month-olds had longer latencies for distraction by the heart rate than behavioral trials (Table 3). The 9-month-old infants took longer to look to the distractor on the behavioral trials. This did not, however, interact with the attention state. The main effect of attentive state approached statistical significance levels, $F(1, 30) = 3.22$, $p = .083$. Infants took longer to look at the distractor during a heart rate deceleration or when judged to be in focused attention (M = 4046.3 ms, log latency M = 7.26, log latency SD = 1.26) than during a heart rate acceleration or casual attention trial (M = 2486.9 ms, log latency M = 6.98, log latency SD = 0.99).

The main goal of the study was to assess the relation of the heart rate and behavioral measures of at-

1. The ANOVA analyzing the a priori experimental manipulations used a subset (n = 33; 11 at each age) of the total sample (N = 56). These data were for participants that successfully completed at least one trial in each trial type. This subset was created to get a balanced factorial design for the repeated measure (trial type). Analyses for post hoc behavioral judgments and heart rate phases were conducted using all participants (N = 56). Post hoc behavioral ratings were defined according to the fixation type the infant was judged to be in upon presentation of the peripheral stimulus: focused or casual attention. Similarly, post hoc heart rate phases were defined by the phase (deceleration or acceleration) the infant was in when the distractor appeared.

Table 3 Distraction Latencies for Six-, Nine-, and Twelve-Month-Old Infants by Measurement Type

	Age (Months)		
Measurement Type	6	9	12
Heart rate	3371.5	1854.3	5242.1
	(7.16, 1.09)	(6.97, .93)	(7.32, 1.46)
Behavioral	2178.8	3854.8	3846.8
	(6.94, .89)	(7.22, 1.26)	(7.20, 1.27)

Note: The mean distraction latencies are in ms, and the log latency mean and standard deviation are given in parentheses.

tention. Therefore, distraction latency was assessed for the trials that the heart rate and behavior were concordant for attention level. Trials were identified where the experimental manipulation and the post hoc assessment of attention (attentive or inattentive) from the alternate measure were in agreement at the time of distractor onset (e.g., a heart rate deceleration trial with a concurrent off-line judgment of focused attention). The log-transformed distraction latency was analyzed with an age (3) × attentive state (2; heart rate deceleration and focused attention, heart rate acceleration and casual attention) × measurement type (2; heart rate, behavioral) ANOVA.[1] A significant effect of attentive state was found, $F(1, 35) = 6.08$, $p = .019$. Infants took longer to look at the distractor on attentive ($M = 4922.4$ ms, log latency $M = 7.42$, log latency $SD = 1.32$) than inattentive trials ($M = 2557.6$ ms, log latency $M = 7.00$, log latency $SD = 1.04$) when heart rate measures were in concordance with behavioral measures.

Previous research using behaviorally defined (Oakes & Tellinghuisen, 1994; Ruff et al., in press) or heart-rate-defined (Casey & Richards, 1988; Richards, 1987) levels of attentive and inattentive behavior has found distraction latencies were longer during attentive than during inattentive periods of time. The distraction latencies were examined in relation to post hoc ratings of behavior or heart rate to determine if these findings could be replicated. The log-transformed distraction latency was analyzed with an age (3) × fixation type (2; focused attention, casual attention) ANOVA.[1] There was a significant main effect of fixation type, $F(1, 49) = 6.76$, $p = .012$. Infants took longer to look at the distractor during focused ($M = 4496.7$ ms, log latency $M = 7.35$, log latency $SD = 1.28$) than casual attention ($M = 3390.9$ ms, log latency $M = 7.12$, log latency $SD = 1.18$). This replicates previous findings with behavioral ratings of attention engagement. The log-transformed distraction latency was analyzed with an age (3) × heart rate phase (2; deceleration, acceleration) ANOVA.[1] There was a significant main effect of heart rate phase, $F(1, 52) = 4.57$, $p = .037$. Infants took longer to look at the distractor when a heart rate deceleration occurred ($M = 4474.6$ ms, log latency $M = 7.31$, log latency $SD = 1.31$) than when a heart rate acceleration occurred ($M = 2886.7$ ms, log latency $M = 7.07$, log latency $SD = 1.12$). This replicates previous findings with heart-rate-defined levels of attention engagement.

Interbeat Interval Changes and Fixation Judgments

The relation between heart rate changes and ongoing behaviorally defined attention type was examined. Interbeat interval (IBI) was computed on an "interval-by-interval" basis. This was done by assigning IBI values to equal intervals weighted by the proportion of time the beat occupied the interval. The IBI changes were plotted at the point when the heart rate deceleration and acceleration criteria were met. Figure 2 shows these IBI values separately for trials on which focused and casual attention were occurring when the criteria were satisfied. These data were analyzed separately for heart rate deceleration and heart rate acceleration using interval (15) × fixation type (2; focused attention, casual attention) ANOVAs.[2] The IBIs at the heart rate deceleration had significant main effects of interval, $F(14, 742) = 18.36$, $p < .001$, $\epsilon = .2812$, and fixation type, $F(1, 49) = 4.62$, $p = .036$, and a significant interval × fixation type interaction, $F(14, 368) = 3.19$, $p = .017$, $\epsilon = .2812$. There was a larger heart rate deceleration (IBI lengthening) for the trials that had focused attention occurring than those trials where casual attention was

2. The Greenhouse-Geisser (Greenhouse & Geisser, 1959) ϵ-correction procedure was used for ANOVAs involving the heart rate intervals, because repeated physiological measures are known to violate the sphericity assumption of repeated-measures ANOVA (Jennings & Wood, 1976).

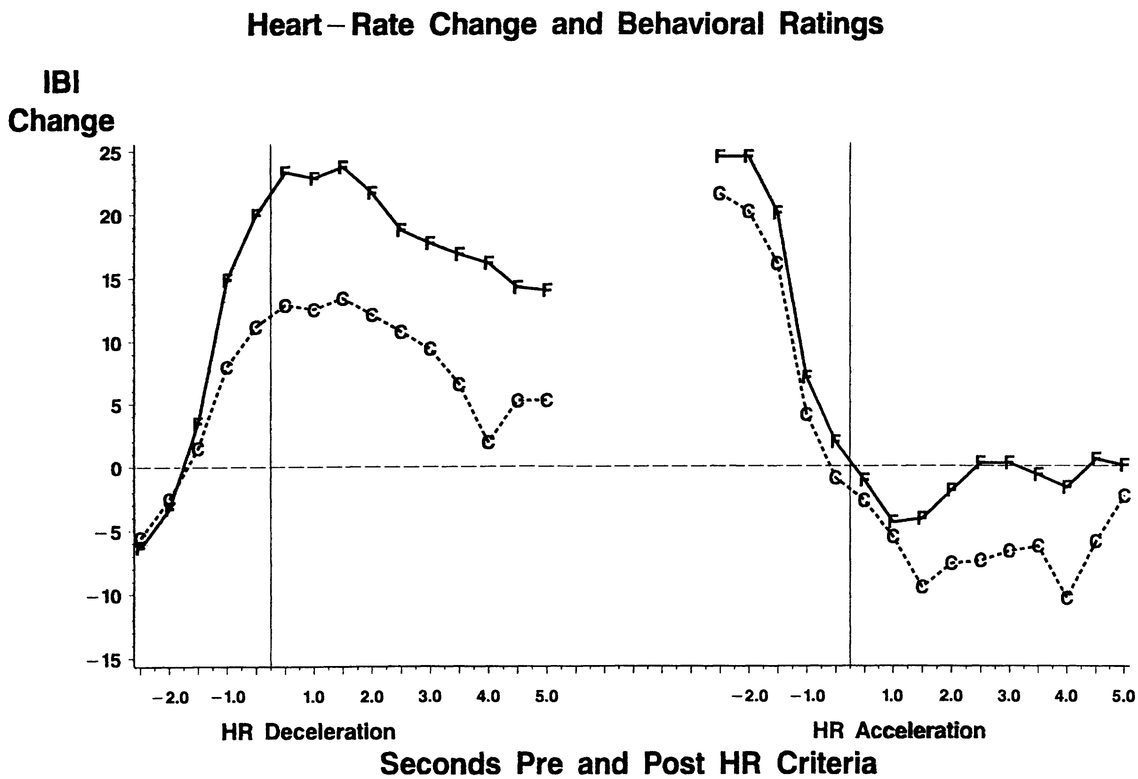

Figure 2 Heart rate 2.5 s before through 5 s after the heart rate deceleration and heart rate acceleration criteria were met (C = casual attention behavioral rating; F = focused attention behavioral rating).

occurring (Figure 2). This was true for the overall mean level (fixation type main effect), and the pattern of the intervals effect was different for the focused and casual attention periods. The IBIs at the heart rate acceleration criteria had only a significant main effect of interval, $F(14, 742) = 65.30$, $p < .001$, $\epsilon = .2975$. The intervals effect reflects the change toward baseline which was implied by the definition of the criteria. There were no differences in the return of heart rate to prestimulus levels for the heart rate acceleration criteria for the two behavioral rating types (Figure 2).

Heart Rate and Behavior Concordance

The relative concordance of the behavioral and heart rate assessment of attention level was examined. The post hoc assessment of attention (inattentive or attentive; behavioral or heart rate) was done for each experimental trial. Table 4 contains the number of trials for the experimental manipulation when the post hoc rating of the alternate measure occurred. Linear categorical modeling was used to evaluate the frequencies in Table 4. There was a significant effect for the concordance between the experimental manipulation of attention and the post hoc assessment of attention from the alternative measure, $\chi^2(3, N = 357) = 15.19$, $p = .001$. The off-line judgment concurred with the experimental manipulation on 58% of the trials (Table 4*c*). There was no effect of age on the frequency distributions for this concordance table ($p = .112$).

There was also a difference in the distributions depending on whether the heart rate or behavioral measures were the experimental manipulations, $\chi^2(3, N = 357) = 14.40$, $p = .002$. Post hoc assessment of behavioral ratings agreed with the experimental manipulations of heart rate on 61% of the trials (Table 4*a*), and this was approximately equivalent for heart-rate-defined attentive (63%) and inattentive (58%) conditions. Post hoc assessment of heart rate agreed with the experimental manipulations defined by behavior on 58% of the trials (Table 4*b*), but this was much stronger for the behaviorally defined trials on the inattentive (75%) than the attentive (40%) condition. Thus, for on-line evaluations of inattentive state, the post hoc analysis strongly concurred (e.g., 67% in Table 4*c*) for either the behaviorally defined or the heart-rate-defined manipulation. However, for the

Table 4 Cell Sizes for Experimental Trial Type by Post Hoc Behavioral and Heart Rate Ratings

a. Heart-rate-defined experimental trial type, and post hoc behavior judgment

	Post Hoc Behavior Judgment		
Trial Type	Attentive Focused Attention	Inattentive Casual Attention	Concordance (%)
Attentive heart rate deceleration	56	32	63
Inattentive heart rate acceleration	31	43	58

b. Behavior-defined experimental trial type, and post hoc heart rate change

	Post Hoc Heart Rate Change		
	Attentive Heart Rate Deceleration	Inattentive Heart Rate Acceleration	Concordance (%)
Attentive focused attention	40	59	40
Inattentive casual attention	24	72	75

c. Experimental trial type and post hoc assessment from the alternative measure (combined 4a and 4b)

	Post Hoc Judgment/Heart Rate Change		
	Attentive	Inattentive	Concordance (%)
Attentive (heart rate deceleration, focused attention)	96	91	51
Inattentive (heart rate acceleration, casual attention)	55	115	67

attentive manipulations, the concordance over all conditions was only 51% (Table 4c), and the concordance was poor for the attentive manipulation defined behaviorally (focused attention) and much better for the attentive manipulation defined by heart rate (sustained attention).

DISCUSSION

Infants took longer to look at a peripheral stimulus during focused attention or sustained attention than during attention termination or casual attention. Distraction latencies were longer when the heart rate changes and behavior ratings were concordant in showing attentive exploration (sustained attention and focused attention) than when both measures showed inattentive fixation (attention termination and casual attention) was in progress. Presentation of a distractor contingent on attention phase resulted in longer latencies to look at a distractor for 6- and 12-month-old infants when heart rate phases, as opposed to behavioral ratings, were used to index attention. In contrast, longer latencies occurred on behavioral trials for 9-month-old infants. Heart rate change was larger when it was assessed behaviorally that the infant was engaged in focused attention.

Previous studies showed that infants exhibit longer distraction times during periods of attentive exploration than inattentive activity (Casey & Richards, 1988; Oakes & Tellinghuisen, 1994; Richards, 1987, in press–b; Ruff et al., in press; Tellinghuisen & Oakes, in press). These findings were replicated when either the behavioral ratings of attention, or the heart rate changes associated with attention, were used separately. Furthermore, infants exhibited the longest distraction latencies when *both* heart rate (sustained attention) and behavior (focused attention) indicated an engaged state of attention. Distraction latencies were shortest when these measures were concordant for inattentive activity (i.e., attention termination in conjunction with casual attention). Episodes of attentive object exploration, as defined by heart rate or behavior, are assumed to represent the active engagement in processing of stimulus information by the infant. If infants are more engaged in information processing during periods of attentive activity, they will be less efficient in monitoring the environment for other stimuli. This effect would result in long distraction latencies for periods of attentive activity. In contrast, an inattentive state would be accompanied by a less intensive engagement with the object, and should result in shorter distraction latencies.

This study illustrated the relation between heart rate and behavioral measures of attention. The analysis of the heart rate (interbeat interval) changes occurring for the heart rate deceleration and acceleration criteria illustrates this relation. The behavioral rating of focused attention and casual attention distinguished the level of the heart rate change, with a larger deceleration of heart rate when focused attention was occurring (Figure 2). This finding suggests that the heart rate changes occurring during focused attention indicate a more intensive attentional engagement than those occurring during casual attention. This heart rate–behavioral rating relation, and the finding that the best discrimination of distraction latency occurred when the two measures were concordant, implies that a unified measure of attention combining focused attention ratings and heart rate changes might be preferable to either measure alone. Theorists have suggested that the level of physiological responses during attention is correlated with the level of cognitive activity (Jennings, 1986, 1992; Kahneman, 1973). The combined occurrence of heart rate and behavioral indices of attention engagement (sustained attention, focused attention) suggests that maximal information processing occurs at that point, relative to the casual attention–sustained attention concordance, or the periods when the heart rate acceleration was met.

Sustained attention and focused attention presumably represent periods of active information processing (e.g., Table 1). In this study, the lengthened distraction time during attentive object exploration was interpreted as indirectly measuring information-processing level in its suppression of the monitoring of other environmental events. More direct measures of information processing have been made during attentive/inattentive behavior. Richards (in press–a) found that infants show better evidence of recognition memory when a "to be remembered" stimulus was presented during heart rate deceleration (sustained attention) than presented when heart rate had returned to prestimulus levels (attention termination). Similarly, the duration of focused attention has been shown to vary systematically with object familiarity, whereas duration of casual attention did not (Oakes et al., 1991; Ruff et al., 1992). These findings, in conjunction with those found in this study, imply that intense information processing occurs when heart rate *and* behavior indicated engaged attention (i.e., sustained attention–focused attention). Alternatively, heart rate responses were not different between behavioral ratings during periods of inattention, as defined by the return of heart rate to its prestimulus level (heart rate acceleration, Figure 2). Concurrent heart rate and behavioral judgments may not be as crucial for identifying episodes of inattention as they are for periods of attention.

This study showed that heart-rate-defined phases of attention apply in a more "naturalistic" setting than has been used in the past. In previous studies of heart rate change and distractor latency, infants sat on their parent's lap in a dimly lit room in front of a bright and interesting computer-generated pattern. The presentation of the pattern was controlled by the experimental protocol. The heart rate changes in this study occurred during object exploration. The exploration of novel objects in this study is similar to situations that infants frequently encounter in their typical environment. This activity also involves the infants' voluntary deployment of attention rather than a response to sudden stimulus onsets.

This study has emphasized the concordance between the heart rate and behavioral measures of attention. However, at least two findings in this study show that heart rate and behavioral ratings were not in perfect agreement. First, the incidence of overlap between the behavioral and heart rate measures, although greater than chance, showed a significant level of "discordant" measurement (Table 4). This was particularly true for the experimental manipulation in which focused attention was judged for 2 s. In that case, a higher incidence of the heart rate acceleration criteria was found than the heart rate deceleration criteria (Table 4*b*). It is possible that this was due to the difficulty of judging focused attention occurrence in the on-line situation. Focused attention is difficult to code because there is some degree of variability across participants. These small individual differences can be overcome during off-line judging as the observer has the opportunity to watch the infant in the experimental session prior to making their judgments. Thus, on-line judgments of focused attention may be more subject to error than on-line judgments of casual attention (Table 4*b*), or off-line judgments of focused or casual attention (Table 4*a*). Second, the changes in heart rate occurring during focused attention were larger than those occurring during casual attention (Figure 2), affirming the behavior–heart rate concordance. Again, however, the heart rate changes occurring defined as "inattentive" (heart rate acceleration, Figure 2) were not distinguished for focused and casual attention. These discordant periods may simply represent the difficult process of on-line evaluations of behavioral ratings of attention. Alternatively, it may be that intermediate levels of attention (intermediate levels of information processing) may be represented by these discordant events. It also may be that the changes in heart rate and the behavioral ratings are indirect measures of distinct attention systems that have different functional relations with the experimental events but that partially overlap in some circumstances. Further research would be needed to detail which of these alternatives is correct.

The post hoc assessment of heart rate or behavior, and the combined ratings, significantly affected distraction latencies. The analysis of distraction latency with the a priori experimental manipulations only approached statistical significance levels for the factor representing level of attention engagement. There are several possibilities why this was not significant. It is possible that this was a problem with statistical power, because only a subset of the total number of participants was used to achieve a balanced repeated measures design. We do not think this is the case, however, because previous studies and this study using these variables singly find a difference between inattentive and attentive periods with comparable numbers of participants. Similarly, unreported analyses from this study that were done with unbalanced designs with all participants found similar results.

Another possibility accounting for the marginal effect of the experimental manipulations on distraction latency is the definition used for the behavioral measures. Each behavioral measure must have occurred for 2 s before the distractor was presented. This was designed to eliminate transient attention phase shifts, or transient on-line judgments. In addition, casual attention was linked sequentially to focused attention. This was done in an attempt to mimic the sequential nature of the heartrate-defined phases (attention termination is sequentially tied to episodes of sustained attention). This definition of casual attention may have been too rigorous. Object play usually is initiated with casual attention, casual attention occurs a larger proportion of time than does focused attention, and casual attention is not necessarily sequentially linked to focused attention (Ruff et al., in press). The lack of a significant "attention" factor effect for the experimentally defined manipulations suggests that such a link is not a suitable distinction for casual attention. This might explain the differentiation of interbeat interval levels for the heart rate deceleration criteria by behavioral ratings, whereas the sequentially defined heart rate acceleration criteria were not closely linked to the ongoing behaviorally defined attention level (Figure 2). The behavioral ratings of attention at time of distractor onset distinguished distraction latencies when the sequential constraints were relaxed.

The relation between the heart rate changes and behavioral ratings of attention illustrated in Figure 2 underscores the importance of the combined assessment of heart rate changes and behavioral ratings of attention in differentiating infants' degree of distractibility. The combined heart rate phases–behavior ratings provided the largest discrimination of distraction latencies. The behavior ratings or the heart rate changes alone did not provide the degree of discrimination between distraction latencies as well as these measures provided when they were concordant. A combined physiological-behavior index may be the best measure of attention engagement in this context. If periods of active attention represent increased information processing, these data suggest that during object examining the greatest levels of information processing are occurring when both heart rate changes and behavioral ratings indicate attentional engagement.

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