Sustained Visual Attention in Young Infants Measured with an Adapted Version of the Visual Preference Paradigm

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CASEY, BETTY JO, and RICHARDS, JOHN E. *Sustained Visual Attention in Young Infants Measured with an Adapted Version of the Visual Preference Paradigm.* CHILD DEVELOPMENT, 1988, **59**, 1514–1521. Phases of infant visual attention were studied using a visual preference procedure that was modified to be similar to a "dual-task," interrupted stimulus procedure. Infants were tested in a cross-sectional design at 14, 20, or 26 weeks of age. The infants were presented with varying and complex TV patterns on a TV monitor. At a delay from the onset of fixation on this stimulus, a similar pattern was presented on an adjacent TV monitor within the infant's field of vision. This secondary stimulus was presented either when heart rate (HR) decelerated significantly below prestimulus level or when the HR returned to prestimulus level. These 2 conditions correspond to sustained attention and attention termination phases of visual attention. The infants were less easily distracted by the secondary stimulus when HR was lower than prestimulus level than when it had returned to prestimulus levels. The amount of HR slowing on the HR deceleration trials increased over this age range, suggesting a developmental increase in sustained attention across this age range. The HR response at the time the infant looked at the secondary stimulus was different for the 2 delay conditions and differed from the HR response at primary stimulus onset. These results confirm the existence of distinct phases of attention during the visual preference procedure and suggest a refinement of the use of simple fixation time as a measure of infant attention with this procedure.

Two frequently used procedures for investigating visual attention in young infants are the infant control procedure (Cohen, 1972; Horowitz, Paden, Bhana, & Self, 1972) and the visual preference method (Fantz, 1963). The infant control procedure consists of the presentation of a visual stimulus for only the length of time that the infant is fixating on it. The measure of visual attention is the duration of fixation on the stimulus. The visual preference method involves the simultaneous presentation of two visual stimuli that generally differ on some dimension. The measure of attention is the duration of fixation on each stimulus, or the percentage of fixation duration on one or the other stimulus. The visual preference procedure has frequently been used to measure infant recognition memory (Fagan, 1982). These methods are based on the assumption that infant attention is a unitary process, and is adequately measured with fixation duration. Different types of cognitive activity, or differing cognitive information processing phases occurring during visual attention, cannot be distinguished using these experimental paradigms.

However, infant visual attention may not consist of a unitary process but may consist of multiple processing phases. Cohen (1972) recorded both fixation time and latency of fixation to differentiate attention-getting and attention-holding processes, respectively. More recently, Ruff (1986) distinguished between two aspects of attention—time to activate attention and time to encode information. Infant heart rate (HR) has often been used as a global measure of infant attention (Berg & Berg, 1987; Von Bargen, 1983). Psychophysiologists investigating infant attention (Graham, 1979; Graham, Anthony, & Zeigler, 1983; Porges, 1976, 1980; Richards, in press–a) have postulated multiple, sequentially ordered phases of attention indexed by infant HR. The orienting response (OR) coincides with stimulus onset and is marked by the initial deceleration in HR. Sustained attention begins after the orienting response and is accompanied by a sustained lowered HR. It is posited that sustained attention facilitates information and stimulus processing. Following the OR and sustained attention, HR often returns to the prestimulus level even though

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infants continue to fixate on the stimulus. The infant is more easily distracted during this phase than during the prior phases, implying that the child is not actively processing the visual stimulus even though fixation continues. This suggests another component of attention which has been referred to as attention termination (Richards, in press–b).

A method has recently been introduced for studying phases of infant visual attention—the interrupted stimulus method (Richards, 1985b, 1987). During fixation on a primary stimulus, a secondary stimulus is presented in the periphery. Active processing of the primary stimulus is assumed to be occurring if the infant cannot be distracted by the secondary stimulus, but not occurring if the infant is easily distractible. The assumption that active processing is inversely related to distractibility is based on a limited resource model of attention (Kahneman, 1973; see Richards, 1987). The interrupted stimulus method was recently used to distinguish the HR-defined phases of sustained attention and attention termination in 14–26-week-old infants (Richards, 1987). The interrupting stimulus was presented either during sustained HR deceleration (sustained attention) or during return of HR to prestimulus level (attention termination). Infants were less easily distracted by the interrupting stimulus when HR deceleration was occurring than when HR had returned to prestimulus level. This finding is consistent with the assumption that HR deceleration during the sustained attention phase is indicative of active cognitive processing. Developmental changes and individual differences were found in the HR response and distraction times of the sustained attention phase but not in the attention termination phase.

In the current study, the visual preference paradigm was adapted to be analogous to the interrupted stimulus paradigm. Two comparable stimuli were presented on adjacent TV monitors. They were presented sequentially (rather than simultaneously) with one stimulus serving the role as the primary stimulus and the other as the interrupting stimulus. One aim of the study was to determine if this adapted version of the visual preference procedure would result in similar findings as those found with the interrupting stimulus method in which the primary and secondary stimuli were qualitatively different (e.g., Richards, 1987). A second aim was to determine if the adapted method could be used to distinguish sustained attention and attention termination. This was done by presenting the secondary stimulus during HR deceleration and when HR had returned to prestimulus levels. If the distraction times, or HR changes, differed for these two procedures, it would call into question the assumption of a unitary cognitive process which has to be made when using visual fixation duration as the measure of visual attention in the visual preference paradigm.

The subjects for this study were 14-, 20-, and 26-week-old infants. These ages were chosen for two reasons. First, across this age range the sustaining of the HR response throughout the period of visual fixation increases (Richards, 1985b, 1987). Second, developmental changes in HR variability and respiratory sinus arrhythmia (RSA) are evident in this period (Harper et al., 1976, 1978). RSA is an empirical description of a systematic rhythmicity in HR that coincides with respiratory phases (Porges, 1976, 1980; Richards, in press–a). It is correlated with infant attention and memory processes, presumably because it indexes cholinergic activity in the central nervous system which inhibits ongoing behavior and allows focusing of attention (Porges, 1976). Thus, this age range may show developmental changes in sustained attention, exhibited in the adapted visual preference paradigm, which parallel the age-related changes in HR variability.

Method

Subjects

Infants were recruited from birth notices published in a Columbia, South Carolina, newspaper. The infants were full term, defined as having birthweights of greater than 2,500 grams and gestational ages of 38 weeks or greater based on the mother's report of her last menstrual cycle. The parents reported that their infant had no pre- or perinatal medical complications. A cross-sectional design was used to sample 30 infants with 10 each at ages 14, 20, and 26 weeks. The mean testing age of infants was 100.2 days (SD = 2.74), 143 days (SD = 3.8), and 185.6 days (SD = 3.44), repectively. Subjects were included who remained in an alert state, characterized by open eyes, no fussing or crying, and responsiveness to experimental presentations. Eight additional infants were excluded because they did not maintain this state.

Apparatus

The infant was held in his or her parent's lap approximately 51 cm from the inner edge of each of two black and white 49-cm (19-inch) TV monitors. The center of each screen was 56 cm from the infant's eyes, and the far edge was 70 cm. The plane of the TVs was parallel to the infant's eyes. The TVs subtended 88° visual angle, with one TV subtending 44° visual angle. There was a visual angle of 48° from center to center of each monitor. A single light-emitting diode was located on the bottom center of each TV screen and blinked at a rate of 3.33 hertz. The surrounding area was covered with a neutral color material. A video camera was located above the TVs, and in an adjacent room a monitor was used to judge infant fixation.

The primary stimuli were recorded segments of "Sesame Street," a series of computer-generated concentric squares of varying size, and a flashing checkerboard pattern (see Richards, 1987). The secondary stimuli were a computer-generated schematic face, a stationary triangle, and the three primary patterns. Each stimulus was presented in a 30-cm^2 area on one of the TV monitors.

Procedure

Respiration and HR were recorded for a 5-min baseline while the infant sat on its parent's lap on a couch. The parent was then seated in a chair in the viewing area with the infant on the parent's lap facing the monitors. There were 12 experimental trials, consisting of four infant control trials and eight interrupted stimulus trials. The infant control trials consisted of the presentation of a primary stimulus until the infant looked away from it. The infant control trials were included to prevent the development of an association of temporal sequencing between the primary and secondary stimuli but were not analyzed. The interrupted stimulus trials consisted of the presentation of the primary stimulus on one monitor followed by some delay, and then the secondary stimulus was presented on the second monitor. Both stimuli remained on until the infant looked toward the secondary stimulus, at which time the primary stimulus was turned off and the secondary stimulus remained on for 5 sec. The duration of the delay of the secondary stimulus was based on one of two conditions: *HR deceleration*—defined as five successive beats with longer heart periods than the median heart period of the five heart beats preceding the presentation of the primary stimulus; *HR acceleration*—defined as five successive beats occurring after a significant HR deceleration, with each beat having a shorter heart period than the median prestimulus heart period. Each infant received four infant control trials, four HR deceleration trials, and four HR acceleration trials.

The 12 experimental trials began with a 5-sec period with no stimulus. Then, the light-emitting diode at the bottom of one of the TVs would blink on and off. When the infant looked toward the blinking light, one of the primary stimuli was presented. Interrupted stimulus trials were restarted if no HR deceleration occurred within 10 sec of fixation onset (10% of trials). They were also restarted if the infant looked away before the onset of the interrupting stimulus (13% and 50% of deceleration and acceleration trials, respectively). The primary stimuli were randomly presented in four three-trial blocks. Two interrupted stimulus and one infant control trial were randomly assigned to the three trials in each block. For the interrupted stimulus trials, the two unique secondary stimuli were each presented twice, and the overlapping stimuli were presented on the remaining four trials, with random assignment of stimulus type over the eight interrupted stimulus trials. The primary stimulus side was randomly selected with no more than two patterns presented on the same side sequentially.

Interrater reliabilities for the judgment of fixation duration were computed between the rater during the experiment and a second rater of a videotape recording of each trial. There was a .99 correlation between the two raters' judged fixation times. Approximately 90% of the trials were judged to be within 1.5 sec of one another by the two raters.

Measurement and Quantification of Physiological Variables

HR and respiration were recorded as in Richards (1987). The online evaluation of HR during HR deceleration and HR acceleration trials was made by an IBM XT microcomputer within 1.5 msec of the criterion beat. For quantitative analyses, the beat-to-beat heart period intervals were converted to rate (bpm) and proportionally assigned to 100-msec intervals for the baseline period (0.1-sec by 0.1-sec HR intervals) and 500-msec intervals for the experimental trials (0.5-sec by 0.5-sec intervals) (see Graham, 1978). Respiration frequency was quantified for each baseline minute by counting the number of breaths that occurred in each minute.

Extent of RSA was computed with spectral analysis methods from the baseline recording. The HR power spectrum was computed from the first 512 0.1-sec intervals of each of the baseline minutes, resulting in a frequency resolution of 0.01953 hertz. The data were transformed by a band-pass filter (Porges, 1986) that passed variability from

0.49 to 1.92 hertz (29.4 to 115.2 bpm), which includes the range of infant respiratory frequencies. The extent of RSA was defined as the power of HR summed over 0.1953 hertz (11.71 breaths per minute) and centered at the modal respiration frequency for that baseline period (Richards, 1985b, 1986, 1987; cf. Harper et al., 1978; Porges, McCabe, & Yongue, 1982). This power measure was transformed by the natural logarithm function for the data analysis. The metric for extent of RSA is the natural logarithm of the "root-mean-squared" variation of HR over the respiration frequency ranges. High and low extent of RSA was defined by separating subjects by a median split within each age. The medians were 1.23, 1.58, and 1.89 for 14-, 20-, and 26-week-olds, respectively.

Results

Heart Rate

Pre- and postinterrupting stimulus.—The HR pattern for the 2.5-sec period preceding and following the onset of the interrupting stimulus was analyzed as the difference in the 0.5-sec values of HR during this period and the mean HR in the 2.5-sec prestimulus period. This change score was analyzed with a procedure (HR deceleration and HR acceleration) × intervals (10 0.5-sec values) ANOVA in order to determine if the experimental manipulations involving the physiological variables had the desired effect. Only the linear, quadratic, and cubic trends of the intervals factor were included in the analysis, and the statistical significance of the intervals effect was based on the "multivariate" approach to testing repeated measures (McCall & Appelbaum, 1973; O'Brien & Kaiser, 1985; Richards, 1980). There were significant procedure, $F(1,27) = 11.75$, $p < .005$, intervals, $F(3,25) = 9.48$, $p < .001$, and procedure × intervals effects, $F(3,25) = 138.56$, $p < .001$, on the HR response during this period. The procedure × intervals interaction was of primary interest. Post hoc Scheffé tests indicated the linear ($p < .001$) and cubic ($p < .05$) trends were significantly affected for the deceleration trials, and the quadratic ($p < .01$) trend was significantly affected on the acceleration trials. Figure 1 shows the HR response for the two procedures, for the 2.5-sec period preceding and following the onset of the interrupting stimulus. As expected, there was a deceleration of HR on the HR deceleration trials and a return of HR to prestimulus level during the HR acceleration trials.

The mean HR difference score from the 2.5-sec period following the interrupting stimulus onset was analyzed with an age (3) × extent of RSA (2) × procedure (2) ANOVA. HR was analyzed from this period because it should be a physiological index of cognitive processing status at that moment and should complement the behavioral index of cognitive processing—distraction time.

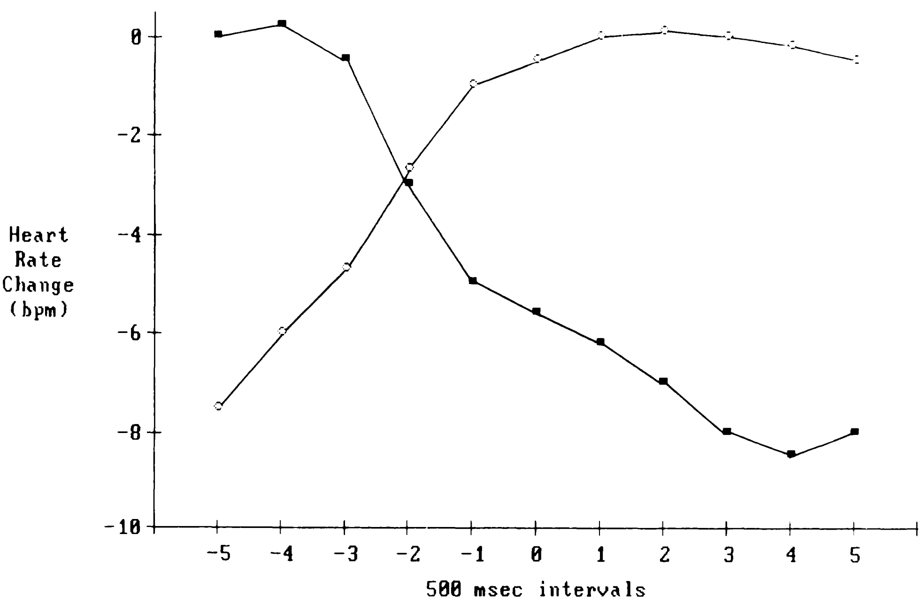

FIG. 1.—Average HR (bpm) in the intervals preceding and following the interrupted stimulus onset for HR deceleration (■) and HR acceleration (○) experimental trials.

There was a significant effect of procedure on the HR response, $F(1,24) = 101.64, p < .001$. This effect parallels the procedure effect reported in the previous analysis. There was a significant interaction of age and procedure, $F(2,24) = 5.35, p < .05$. Post hoc Scheffé tests indicated a systematic increase for the 14-, 20-, and 26-week-olds in the depth of the HR response on deceleration trials (M's = -6.82, -7.215, and -9.89 bpm, respectively; $p < .01$) and a significant difference between ages on the acceleration trials (-2.79, .267, and $-.335$ bpm; $p < .05$). The interaction of the extent of RSA and procedure approached significance, $F(1,24) = 3.36, p = .079$. Infants with large magnitudes of RSA in the baseline had larger HR responses than those infants with low magnitudes of RSA (M's = -9.9 and -8.8, respectively), but only for the HR deceleration trials. It is believed that this finding only approached statistical significance as the result of a smaller sample size and a less powerful test of the interaction than previous studies (e.g., Richards, 1987).

Response to interrupting stimulus.—The pattern of HR values during the 5-sec period beginning with the infant's look toward the secondary stimulus was analyzed. This is the "onset" of the interrupting stimulus, as defined by the infant looking toward it and away from the primary stimulus. It differs from the primary stimulus onset in that it does not begin at the time the stimulus is presented, but rather when the infant looks toward it. The difference between the 0.5-sec HR values in this period and HR mean value from the 2.5-sec prestimulus period was analyzed with an age (2) × extent of RSA (2) × procedure (2) × intervals (10) ANOVA. There was a procedure effect, $F(1,24) = 26.29, p < .001$, and a procedure × intervals interaction, $F(3,72) = 6.69, p < .005$. The procedure effect was significant only for the linear trend, indicating a linear difference between the HR response on the HR deceleration and HR acceleration trials. The right half of Figure 2 shows the HR response following fixation to the interrupting stimulus for the HR deceleration trials (sustained attention) and HR acceleration trials (attention termination). The left half shows the HR response occurring at the onset of the primary stimulus. (The onset HR response was not statistically analyzed because of the differing trial durations due to the use of infant-determined duration.) The level of HR remained below the prestimulus level during fixation on the secondary stimulus for the HR deceleration trials and then began to return to prestimulus level. There was a deceleration of HR on the HR acceleration trials, but not to the extent of the HR response to the primary stimulus onset.

Distraction Time

The interval from the actual onset of the interrupting stimulus to the fixation of it (distraction time) was analyzed with an age (3) ×

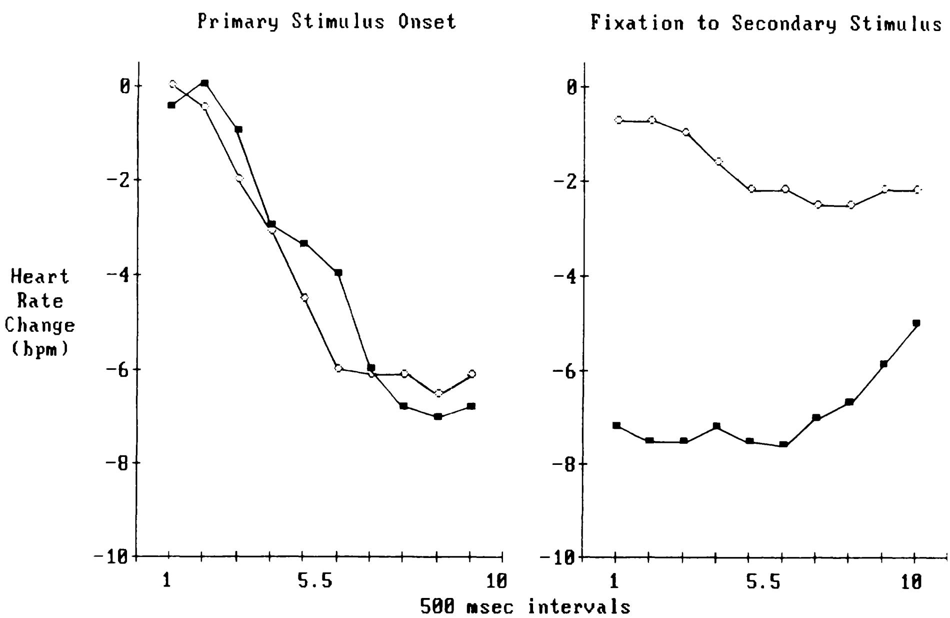

FIG. 2.—Average HR (bpm) in the intervals following primary stimulus onset (left panel) and fixation toward the secondary stimulus (right panel) for HR deceleration (■) and HR acceleration (○) trials.

extent of RSA (2) × procedure (2) ANOVA. Because of positive skewness and nonnormality typical of reaction time data, the time variable was transformed by the natural logarithm function. The transformation corrected skewness and resulted in a normally distributed variable. There was a main effect of age on distraction time, $F(2,24) = 6.86$, $p < .005$. The latency of distraction by the interrupting stimulus systematically decreased with age (M's = 7.7, 4.4, and 2.8 sec, for 14-, 20-, and 26-week-olds, respectively). The procedure effect approached statistical significance, $F(1,24) = 4.01$, $p = .056$. The distraction times on the HR deceleration trials were longer than during the HR acceleration trials (M's = 5.8 and 4.4 sec).

Discussion

The adapted visual preference method produced similar results to those found with the interrupted stimulus method (Richards, 1985b, 1987). On HR deceleration trials (sustained attention), the infant was less likely to be distracted by the secondary stimulus and HR remained below prestimulus levels. The infant was more easily distracted when HR had returned to prestimulus levels (attention termination). The infants often looked away on the HR acceleration trials before the physiological criterion was met for the presentation of the secondary stimulus. Many of those trials were due to the specific criterion used in this study, for example, HR was returning toward the prestimulus level but had not quite reached it, or HR returned to a new tonic level that was below the prestimulus level but was maintained in the subsequent absence of visual stimulation. This finding also implies that attention termination can be marked behaviorally by the infant looking away, and at least equally often can be marked physiologically by the return of HR to the prestimulus level. The physiological measures of phases of attention complement the traditional behavioral measures.

Level of RSA differentiated HR responses on the HR deceleration trials but not on the HR acceleration trials, although this effect was only marginally significant. The RSA × procedure interaction on HR only approached statistical significance during post-interrupted stimulus intervals. The power of this test may have been limited by the sample size. In a similar study (Richards, 1987) with more subjects, HR level on the HR deceleration trials was significantly different for RSA groups, but not on the HR acceleration trials. An alternative reason for the power of this effect may be in the nature of the presentations used in the current study. The stimuli in the present study were more intense (two large TV displays) and the detection of the secondary stimulus may be simpler (minimal distance between displays). That the detection was "easier" to make is not supported by the distraction time durations, which were similar to those found by Richards (1987).

Developmental changes in the sustained attention and attention termination phases were also similar to those found previously. There was a significant increase with age of the HR response on the HR deceleration trials but not on the HR acceleration trials. This parallels the increasing sustaining of the HR response on interrupted trials found in Richards (1985b) and replicates the finding of Richards (1987) of high-RSA infants. The sustaining of the HR response through the period of sustained attention by the older infants is a sign of the continued holding of available resources for viewing the primary visual stimulus (see Jennings, 1986). The distraction times systematically decreased across the ages and did not interact with the HR deceleration and HR acceleration procedures. The distraction time decrease makes it appear that the older infants are more distractible than are the younger infants. However, there seems to be an increase in the quality of attention directed toward visual stimuli across these ages, that is, sustaining of the HR response throughout the period of fixation on the stimulus. It is our interpretation that the decreased distraction time across ages is due to increases in processing efficiency resulting in quicker processing of the available stimulus information. This interpretation is supported by research which shows, for example, that the time needed to become familiar with a visual stimulus in a memory recognition task decreases with age (e.g., Rose, 1983; Zelazo & Kearsley, 1982).

An important finding was the difference in the HR response following fixation toward the secondary stimulus during sustained attention and attention termination. On HR deceleration trials, HR remained stable and below the prestimulus level when the infant looked toward the interrupting stimulus. If the sustained HR response indexes active cognitive processing, this implies that the infant was distracted by the secondary stimulus even though sustained attention was still occurring to the primary stimulus, and actively attends to the secondary stimulus. This type of fixation shift on the part of the infant may represent a process similar to active comparison of two simultaneously presented stimuli. If, however, HR had returned to prestimulus level (HR acceleration trials), a small deceleration of HR occurred. The response was similar in form to the HR response to the primary stimulus but was smaller in level. This difference in the "onset response" to a stimulus in these three attention phases underscores the importance of assessing the status of the cognitive processing system in analyzing the attentional response of the infant. In terms of the visual preference paradigm, one must evaluate cognitive processing status when the infant shifts fixation from one stimulus to another to understand the type of stimulus processing that is occurring.

The difference between the HR onset response to the primary stimulus, and to the secondary stimulus during the HR acceleration trials, suggests that the attention termination phase is followed by a refractory period during which an optimal HR deceleration cannot occur, and perhaps a resistance to attention engagement. Parallel findings come from studies of the HR response that occurs at stimulus termination—the HR offset response. The termination of a stimulus of short duration (7–10 sec) is associated with a brief and small HR deceleration (Berg, 1972, 1974; Richards, in press–b). The termination of a stimulus of longer duration (greater than 20 sec) results in a larger deceleration in HR (Lewis, 1971; Richards, in press–b). However, stimulus duration alone does not fully determine the offset response. Trials of duration across this range (7–20 sec), but which end at the return of HR to prestimulus level or when the infant voluntarily looks away, result in a HR response of similar magnitude to stimuli of short duration (Richards, in press–b). The full HR OR to stimulus onset, and a large HR response at stimulus offset, may require that the attention termination phase be completed for several seconds.

The separation of components of attention by the adapted visual preference method parallels findings observed with the interrupted stimulus method. The visual preference method as currently used is a valuable experimental procedure. These results suggest a refinement of the use of fixation duration as the major dependent variable and the assumption that visual attention is a unitary process. For example, percentage of fixation time is used in this paradigm to infer stimulus discrimination, or novel stimulus preference. However, knowing the type of attention displayed, the length or percentage of active attention to each stimulus, or the phase in which stimulus comparisons are made would improve the statements about stimulus discrimination, or recognition memory, that could be made employing this paradigm. The observed differences between HR defined phases of attention with this procedure indicate its applicability to earlier research asserting the existence of components of attention (Graham, 1979; Porges, 1976; Richards, in press–a; Ruff, 1986). The next step to understanding infant visual attention may be through the evaluation of task performance during the HR defined phases with this adapted method.

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