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Sustained Visual Attention in 8-Week-Old Infants

JOHN E. RICHARDS

University of South Carolina

Sustained visual attention was studied in 8-week-old infants. The infants were presented with varying and complex 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 when heart rate slowed significantly below prestimulus level, when the heart rate returned to prestimulus level, or at 3 or 7 s following the onset of the first stimulus. The infants were less easily distracted by the secondary stimulus when heart rate was lower than prestimulus level than when it had returned to prestimulus levels. The amount of heart rate slowing on the heart rate deceleration trials was significantly correlated with baseline amplitude of respiratory sinus arrhythmia (i.e., heart rate variability). Distraction time was positively correlated with heart rate variability on heart rate deceleration and heart rate acceleration trials. These results replicate the measurement of sustained attention in older infants and extend the study of the development of sustained attention earlier in life. However, there may be a dissociation between behavioral and physiological indices of sustained attention which become more closely associated in the next 2 to 3 months.

infant Heart Rate (HR) sustained attention
Respiratory Sinus Arrhythmia (RSA)

Infant attention has been hypothesized to consist of multiple phases. Distinctions can be made between attention-getting (attention activation; stimulus orienting), attention-holding (encoding, sustained attention), and attention termination, based on behavioral (e.g., Cohen, 1972; Ruff, 1986b) and psychophysiological evidence (Graham, Anthony, & Zeigler, 1983; Porges, 1976, 1980; Richards, 1988). Recent research on infants in the first 6 months of life has focused on the sustained attention phase (Richards, 1988). Sustained attention begins after initial attention-getting processes and is thought to facilitate information and stimulus processing (Porges, 1976). Sustained attention is marked by a sustaining of the lowered heart rate which was initiated in the stimulus-orienting phase of attention (Porges, 1976; Richards, 1988).

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Correspondence and requests for reprints should be sent to John E. Richards, Department of Psychology, University of South Carolina, Columbia, SC 29208.

Visual sustained attention has been examined in 14- to 26-week-old infants (Casey & Richards, 1988; Richards, 1985, 1987, 1989). Those studies have reported that the sustaining of the heart rate response throughout the period of visual fixation increased across the age range from 14 to 26 weeks. The sustained heart rate response that occurred during sustained attention was very closely associated with amplitude of respiratory sinus arrhythmia (RSA). Respiratory sinus arrhythmia is an empirical description of a systematic rhythmicity in heart rate that coincides with respiratory phases (Grossman, 1983; Porges, McCabe, & Yongue, 1982). It may be associated with sustained attention because it indirectly assesses central nervous system (CNS) cholinergic activity which is involved in the inhibition of ongoing behavior, allowing the focusing of attention which is characteristic of sustained attention (Porges, 1976, 1980). The developmental changes found in the sustained heart rate response during sustained attention are closely associated with developmental changes in RSA which occur during this age period (Richards, 1989). Amplitude of RSA has also been shown to be positively correlated with behavioral indices of infant attention and cognition, including level of sustained attention (Richards, 1987) and infant recognition memory (Linnemeyer & Porges, 1986).

The study of sustained attention development in early infancy is important for several reasons (Richards, 1988). It is likely that information acquired during processing of visual stimuli comes during initial stimulus orienting and subsequent sustained attention. If sustained attention is not engaged, or has ceased, the infant may look in the direction of a visual stimulus without processing the stimulus information. Because the level of sustained attention increases over the first few months of infancy, the older infant can extract information from visual stimuli more effectively than younger infants. Thus, for example, familiarity with a visual object should be acquired during stimulus orienting and sustained attention. The increase with age in recognition memory scores to same exposure duration suggests that the information necessary for recognition is acquired more efficiently as infants get older (Rose, 1983; Zelazo & Kearsley, 1982). This may be due to sustained attention increases. Developmental and individual differences in the RSA–sustained attention relation may be paralleled by immature or pathological patterns of attention in at-risk infants (Richards, 1988). The RSA amplitude is smaller in high-risk infants, such as preterm infants with Respiratory Distress Syndrome (RDS) or asphyxiated infants (Divon et al., 1986; Kero, 1973; Rother et al., 1987). The heart rate response of premature infants with perinatal or postnatal illness is immature, or of poor quality, compared with full-term infants (Fox & Lewis, 1983; Von Bargen, 1983). High-risk preterm infants at 6 and 9 months do poorly than full-term or healthy preterm infants on behavioral measures of sustained attention (e.g., object examination time, Ruff, 1986b; cf. recognition memory, Rose, 1983). The association in the high-risk infant of low RSA amplitude, weak attention-linked heart rate responses, and poor quality behavioral sustained attention may be partially understood by examining sustained attention in very young infants with similar RSA levels.

The present study extended the study of sustained attention to 8-week-old infants, using an "interrupted stimulus" procedure. The procedure consisted of the presentation of a primary stimulus and, following fixation on the primary stimulus, a secondary stimulus in the periphery. The secondary stimulus experimentally "encourages" fixation termination on the primary stimulus to occur at the termination of sustained attention (Richards, 1988). Active processing of the primary stimulus is assumed to be occurring if the infant continues to fixate, but not occurring when the infant can be distracted by the secondary stimulus. In the absence of the secondary stimulus, infants may continue to direct fixation toward the primary stimulus even though sustained attention has ceased (e.g., Richards, 1987). The duration of sustained attention was therefore defined as the length of time the infant continues to fixate on the primary stimulus in the presence of the secondary stimulus. The secondary stimulus presentation was delayed from the onset of the primary stimulus. It was presented either 3 or 7 s after the primary stimulus onset, when heart rate deceleration was occurring (sustained attention phase) or when heart rate was returning to prestimulus levels (attention termination phase). The infant's heart rate, heart rate variance (HRV), and amplitude of RSA were recorded in a baseline period in order to relate them to heart rate and fixation responses in attention. The amplitude of RSA increases from 1 to 6 months of age (Harper et al., 1978) and should therefore be smaller at this age than at 3 months of age. Because sustained attention development is closely tied with RSA amplitude, the lower amplitude of RSA in 8-week-olds should be correlated with decreased levels of sustained attention. This should include both behavioral and physiological indices of sustained attention.

METHODS

Subjects

Infants were recruited from birth notices published in a Columbia, South Carolina, newspaper. The infants were full term, with birth weights of greater than 2500 gms and gestational ages of 38 weeks or greater based on the mothers' report of their last menstrual cycle. The parents reported their infant had no pre- or perinatal medical complications. A total of 59 infants were tested at 8 weeks of age. The mean testing age of infants was 57.56 days ($SD = 3.12$). Subjects were included who remained in an alert state, characterized by open eyes, no fussing or crying, and responsiveness to experimental presentations. Of the infants tested, 28 infants met the inclusion criteria and were included in the study (testing age = 57.60 days, $SD = 3.20$). The remaining 29 infants were excluded because they did not maintain this state. There were no significant differences between the included and excluded infants in testing age, baseline heart rate, baseline HRV, or baseline RSA.

Apparatus

The infant was held in his/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 Hz. The surrounding area was covered with a neutral-colored material. A video camera was located above the TVs, and in an adjacent room a monitor was used to judge infant fixation.

The visual stimuli were computer-generated patterns. They were displayed in a 30-cm square area on one of the TV monitors. There were eight patterns, such as a series of concentric squares of varying size, a flashing checkerboard pattern, a rotating star, and a schematic face. These patterns in pilot studies had been found to elicit first fixation durations of greater than 10 s at older ages (14 to 26 weeks old).

Procedure

Respiration and heart rate were recorded for 5 min while the infant sat on his or her 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. Stimuli were presented on the two TVs for two trials in order to acquaint the infant with their location. Each trial consisted of a 5-s period with no stimulus followed by the presentation of the stimuli. The infant-control procedure for stimulus presentations (Cohen, 1972; Horowitz, Paden, Bhana, & Self, 1972) was used such that the TVs remained on as long as the infant was looking at either TV, and the trial was terminated when the infant looked away from the TVs.

There were 12 experimental trials, consisting of 4 infant-control trials and 8 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 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 s.

The duration of the delay of the secondary stimulus was based on one of four conditions: *3-second*—presented when 3 s had elapsed; *7-second*—presented when 7 s had elapsed; *heart rate 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; *heart rate acceleration*—defined as five successive beats with shorter heart periods than the median pre-stimulus heart period, and which must have followed a significant heart rate deceleration. Two six-trial blocks were used, each with two infant-control trials and one trial from each of the four types of interrupted stimulus criteria, with procedure order randomly chosen within each six-trial block.

The 12 experimental trials began with a 5-s 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 towards the blinking light, one of the primary stimuli was presented. Heart rate deceleration and heart rate acceleration trials were restarted if no heart rate deceleration occurred within 10 s of fixation onset (40% of trials). They were also restarted if the infant looked away before the onset of the secondary stimulus (17%, 58%, 5%, and 23% of deceleration, acceleration, 3-second, and 7-second trials, respectively). The eight visual stimuli were divided into two sets with four each, and a primary stimulus and secondary stimulus were drawn from each set. The four stimuli in the two sets were randomly presented in three four-trial blocks and had equal probabilities on each trial of being a primary or secondary stimulus. The primary stimulus side alternated between the two TVs.

Interrater reliabilities of fixation duration judgment were computed between the rater during the experiment and a second rater of a videotape recording of each trial. Over all the subjects, the raters disagreed about the presence or absence of a fixation away from the primary stimulus on 7% of the trials. For the remaining trials, there was a correlation of .99 between the two raters' judged fixation times. Approximately 80% of the trials were judged to be within 1.5 s of one another by the two raters.

Measurement and Quantification of Physiological Variables

The online evaluation of heart rate during heart rate deceleration and heart rate acceleration trials was made by an IBM PC XT microcomputer within 1.5 ms of the criterion beat. For quantitative analyses, the beat-to-beat heart period intervals were converted to rate (bpm) and proportionally assigned to 100-ms intervals for the baseline period (0.1-s by 0.1-s heart rate intervals) and 500-ms intervals for the experimental trials (0.5-s by 0.5 s intervals; (see Graham, 1978, or Richards, 1980). Rate rather than period was chosen as the cardiac function to coordinate the heart response with fixation patterns in the experimental trials. Baseline mean heart rate was defined as the average of the 100-ms bins, and variance of heart rate was the standard deviation of heart rate of the 100-ms bins. The mean baseline heart rate for the subjects was 152.60 (SD=9.80), and the average heart rate variance was 7.35 (SD=2.23).

Amplitude of RSA was computed with spectral analysis methods from the baseline recording. The heart rate power spectrum was computed from the first 512 0.1-s intervals of each of the baseline minutes, resulting in a frequency resolution of 0.01953 Hz. The data were transformed by a band-pass filter (Porges, 1986) which passed variability from 0.49 to 1.92 Hz (29.4–115.2 bpm), which includes the range of infant respiratory frequencies. The amplitude of RSA was defined as the power of heart rate summed over 0.1953 Hz (11.71 breaths per minute) and centered at the modal respiration frequency for that baseline period (Richards, 1986; cf. Harper et al., 1978; Porges et al. 1982). This power measure was transformed by the natural logarithm function for the data analysis. Mean RSA amplitude was 0.68. In previous studies with older infants the amplitude of RSA was used to do a median split for an "extent of RSA" factor in order to look at the interaction between RSA amplitude and age. Because only one age was tested in the present study, RSA was used as a quantitative index rather than a qualitative factor.

Experimental Design for Statistical Analysis

Within-subject factors were procedure (heart rate deceleration, heart rate acceleration, 3-second, 7-second, infant control) and intervals (500-ms intervals). The intervals factor was corrected by the Hunyh-Feldt procedure to control for lack of homogeneity of covariances in the repeated-measures effects (Richards, 1980; Vasey & Thayer, 1987). Only the linear, quadratic, and cubic orthogonal polynomial trends were tested in the intervals effects, because these are interpretable in the context of heart rate change research. Error rate in post-hoc tests was controlled with a Bonferonni-type correction.

RESULTS

Heart Rate

Stimulus Onset Response. Heart rate from the 7.5 s following the onset of the primary stimulus was analyzed as the difference in the 0.5-s values from this period and mean heart rate in the 2.5-s prestimulus period, with a Procedure(5) × Intervals(15) ANOVA. The only significant effect was an Intervals main effect, $F(3,24) = 23.02$, $p < .05$. The linear and quadratic polynomials for the Intervals effect were significantly affected, $ps < .033$. Heart rate decelerated approximately -3.6 bpm by 7.5 s following the primary stimulus onset.

Pre- and Postsecondary Stimulus. Analyses were done of heart rate for the 2.5-s periods preceding and following the secondary stimulus onset in order to determine if the experimental manipulations involving the physiological variables resulted in heart rate deceleration and acceleration as expected. The results of these analyses replicated those of Richards (1987) and Casey and Richards (1988). Figure 1 shows the heart rate response for the four procedures, for the 2.5-s period preceding and following the onset of the second-

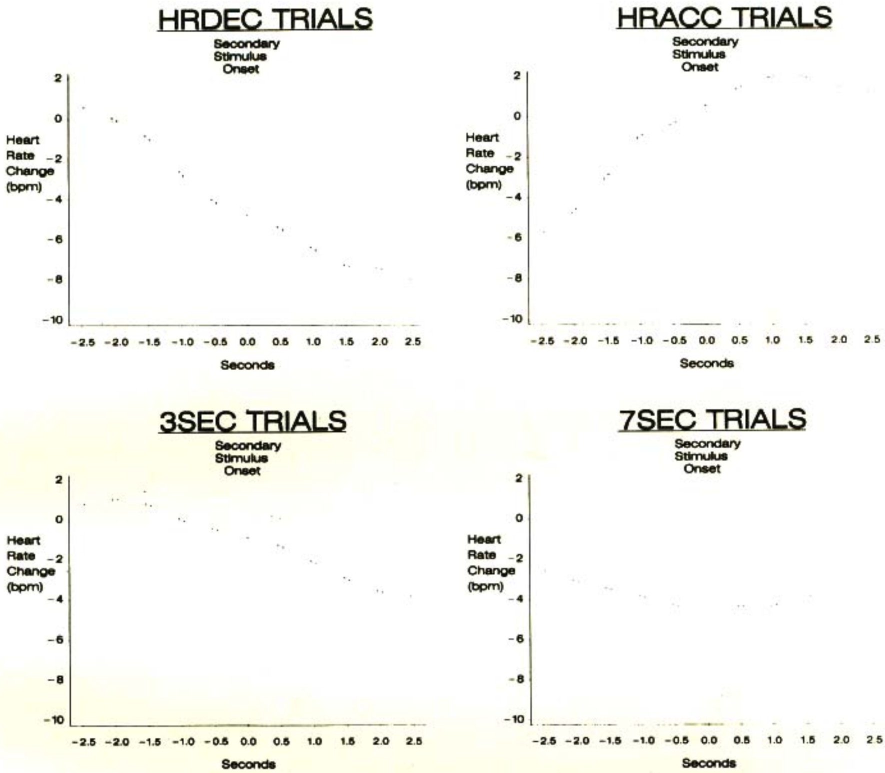

Figure 1. Heart rate response for 2.5-s period preceding and following the onset of the secondary stimulus (SS) for the four secondary stimulus procedures.

ary stimulus. As expected from the manipulation, there was a deceleration of heart rate on the heart rate deceleration trials and a return of heart rate to prestimulus level during the heart rate acceleration trials. Heart rate was decelerating on the 3-second trials, like the onset response to the primary stimulus. Heart rate on the 7-second trials was lower than prestimulus level and remained stable throughout this period.

The correlations between the baseline physiological variables and the mean heart rate difference score from the 2.5-s period following the secondary stimulus onset are presented in Table 1. Heart rate during this period was negatively correlated on the heart rate deceleration trials with RSA and with heart rate variance. The negative correlation indicates that large decelerations were associated with large levels of baseline heart rate variability. Mean heart rate level in the baseline was negatively correlated with the heart rate change on the 3-second procedure. The baseline physiological parameters were not significantly correlated with heart rate change on the heart rate acceleration or the 7-second trials.

TABLE 1
Correlations Between the Baseline Physiological Variables and the Heart Rate Change During the 2.5-S Period Following the Onset of the Secondary Stimulus

	Experimental Procedure			
	Heart Rate Deceleration	Heart Rate Acceleration	3-Second	7-Second
Heart rate	−.06	.05	−.35*	−.20
Heart rate variance	−.36*	.05	−.14	−.02
RSA	−.46**	−.09	.20	−.05

* $p<.05$. ** $p<.01$.

Distraction Time

Distraction time was defined as the duration of time following the secondary stimulus onset until fixation towards the secondary stimulus, that is, how long the infant continued to look at the primary stimulus in the presence of the secondary stimulus. The natural logarithm of the distraction time score was used to approximate a normal distribution, because duration measures are often skewed. This variable was analyzed with a Procedure(4) ANOVA with the four interrupted stimulus procedures. The Procedure effect approached statistical significance, $F(3,78)=2.48$, $p=.067$. The mean distraction times were 7.7, 5.1, 8.0, and 8.7 s for the heart rate deceleration, heart rate acceleration, 3-second, and 7-second trials, respectively. The difference between the heart rate acceleration and deceleration procedures was in the anticipated direction but was not statistically significant, $p=.078$.

Distraction times on the 3- and 7-second trials were further analyzed by splitting those trials into three groups based on the level of heart rate at the point of the secondary stimulus onset. Three heart rate levels were established: (a) heart rate less than the average on the heart rate deceleration trials (−6.9 bpm); (b) heart rate greater than that on the heart rate acceleration trials (1.6 bpm); (c) heart rate level between the levels of (a) and (b). These levels were chosen to make a comparison of distraction times between the heart rate defined trials (heart rate deceleration and acceleration) and the level of heart rate at a fixed point in time (3 or 7 s). When heart rate was still decelerating, average distraction times on the 3- and 7-second trials were 10.77 and 12.2 s, respectively. If heart rate had returned past the prestimulus level, distraction time was the shortest, 6.76 and 6.51 s for the 3- and 7-second trials, respectively. Finally, when heart rate level was at an intermediate level, distraction time was at an intermediate level, 7.94 and 7.31 s, respectively.

The correlations between the baseline variables and the distraction time are presented in Table 2. Baseline RSA was positively correlated with the distraction time on the heart rate deceleration trials. Heart rate variance was positively correlated with distraction time on the heart rate acceleration trials. None of the other correlations was statistically significant.

TABLE 2
Correlations Between the Baseline Physiological Variables and Distraction Time (Seconds) for the Interrupted Stimulus Procedures, Consisting of the Time From the Secondary Stimulus Onset to Looking Away From the Central Stimulus

	Experimental Procedure			
	Heart Rate Deceleration	Heart Rate Acceleration	3-Second	7-Second
Heart rate	−.08	.12	.02	−.23
Heart rate variance	.02	.44**	−.16	−.15
RSA	.50**	.32	.14	.10

* $p<.05$. ** $p<.01$.

DISCUSSION

This study replicates with 8-week-old infants two findings about sustained visual attention found with 14- and 26-week-old infants (Casey & Richards, 1988; Richards, 1987, 1989). First, when the heart rate response to a visual stimulus was still in progress, the infant was less likely to be distracted by the secondary stimulus than when the heart rate response had ended. This occurred both when the heart rate response was defined a priori (heart rate deceleration and acceleration trials) or when existing heart rate levels were examined at a fixed point in time (3- and 7-second trials). Sustained heart rate responding coincided with behavioral measures of active attention. Second, RSA was positively correlated with the magnitude of the heart rate response on the trials in which sustained attention was occurring (heart rate deceleration) and for the sustained component of attention. Respiratory sinus arrhythmia was also correlated with the behavioral measure of sustained attention—distraction time—which measures how long the infant is engaging in active attention directed toward the primary stimulus. Thus RSA is positively correlated with sustained attention level in 8-week-old infants in a similar manner as has been found in older infants. Thus study again supports the theory that RSA is an index of individual differences in infant sustained attention (Porges, 1976, 1980; Richards, 1988).

The data extend the findings of developmental changes in sustained attention that have been reported for older infants. The heart rate response to stimulus onset was smaller (3.5 bpm) compared with previous research (7–8 bpm). However, once it reached its maximum (Figure 1, heart rate deceleration procedure, 7-second trials), it was approximately equivalent. Table 3 presents some current findings along with means of similar data from 14- to 26-week-old infants (Casey & Richards, 1988; Richards, 1987, 1989). Baseline heart rate mean decreases over this age range, whereas baseline RSA amplitude increases, as has been found by other researchers (Harper, Hoppenbrouwers, Sterman, McGinty, & Hodgman, 1976; Harper et al., 1978; Katona, Frasz, & Egbert,

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). New York: Academic.

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

Porges, S.W. (1986). V: An accurate method of quantifying RSA. *Psychophysiology, 23,* 414.

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

Posner, M.I., & Presti, D.E. (1987). Selective attention and cognitive control. *Trends in Neuroscience, 10,* 13–17.

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

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

Richards, J.E. (1986). Power spectral analysis quantification of respiratory sinus arrhythmia. *Psychophysiology, 23,* 414.

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

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

Richards, J.E. (1989). Development and stability in visual sustained attention in 14-, 20-, and 26-week-old infants. *Psychophysiology, 26,* 422–430.

Rose, S.A. (1983). Differential rates of visual information processing in full-term and preterm infants. *Child Development, 54,* 1189–1198.

Rother, M., Zwiener, U., Eiselt, M., Witte, H., Zwacka, G., & Frenzel, T. (1987). Differentiation of healthy newborns and newborns-at-risk by spectral analysis of heart rate fluctuations and respiratory movements. *Early Human Development, 15,* 349–363.

Ruff, H.A. (1986a). Components of attention during infants' manipulative exploration. *Child Development, 57,* 105–114.

Ruff, H.A. (1986b). Attention and organization of behavior in high-risk infants. *Journal of Developmental and Behavioral Pediatrics, 7,* 298–301.

Schiller, P.H. (1985). A model for the generation of visually guided saccadic eye movements. In D. Rose & V.G. Dobson (Eds.), *Models of the visual cortex.* New York: Wiley.

Vasey, M.W., & Thayer, J.F. (1987). The continuing problem of false positives in repeated-measures ANOVA in psychophysiology: A multivariate solution. *Psychophysiology, 24,* 479–486.

Von Bargen, D.M. (1983). Infant heart rate. *Merrill-Palmer Quarterly, 29,* 115–149.

Watanabe, K., Iwase, K., & Hara, K. (1973). Heart rate variability during sleep and wakefulness in low-birthweight infants. *Biology of the Neonate, 22,* 87–98.

Zelazo, P.R., & Kearsley, R.B. (1982, March). Memory formation for visual sequences: Evidence for increased speed of processing with age [Abstract]. *Paper presented at the ICIS Conference,* Austin, TX.

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