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Individual Differences in Infants' Recognition of Briefly Presented Visual Stimuli

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Infants' recognition memory has been shown to be related to individual differences in look duration and level of heart period variability. This study examined the effect of individual differences in these 2 measures on infants' recognition of briefly presented visual stimuli using a paired-comparison recognition-memory paradigm. A sample of 35 full-term infants was studied longitudinally at 14, 20, and 26 weeks of age. Recognition memory for briefly presented stimuli was tested in 6 experimental conditions, with delays corresponding to different heart-rate-defined phases of attention. The 20- and 26-week-old infants, and infants with high levels of heart period variability, generally showed more evidence of recognition memory for briefly presented visual stimuli. Greater evidence of recognition memory was observed when stimuli were presented during sustained attention. Infants with more mature baseline physiological responses show greater evidence of recognition memory, and stimulus and procedural factors may be more important for the study of individual differences in infant visual attention than has previously been suggested.

Recognition memory in young infants has typically been studied with a paired-comparison procedure in which infants are first exposed to a familiarization stimulus for a predetermined length of time and then are presented with the familiar

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and a novel stimulus. Recognition memory is inferred by infants' longer looking times to the novel stimulus relative to the familiar one (a novelty preference; see Fagan, 1974). Interest in individual differences influencing infants' paired-comparison performance has been fueled by the finding that novelty preference scores are modestly correlated with other measures of cognitive functioning both in infancy and later in childhood (see Colombo, 1993; Rose & Feldman, 1997). Thus, infants' performance in paired-comparison procedures has been interpreted as demonstrating individual differences in early cognitive function (Fagan, 1984). The goal of the research reported here was to examine the effect of individual differences in attention on infants' recognition memory for briefly presented visual stimuli.

Infants' recognition memory has been shown to be related to individual differences in both behavioral and physiological measures of attention. First, individual differences in measures of overt looking behavior are related to recognition memory. Infants vary in their characteristic length of looking at static visual patterns during habituation sessions, with short-looking infants having a greater number of shorter duration looks toward stimuli than long-looking infants (Colombo & Mitchell, 1990). In paired-comparison paradigms, short-looking infants achieve significant novelty preference scores with shorter familiarization exposure times than do long-looking infants (Colombo, Freeseman, Coldren, & Frick, 1995; Colombo, Mitchell, Coldren, & Freeseman, 1991; Frick & Colombo, 1996; Jankowski & Rose, 1997). Look duration is a moderately stable individual difference and is significantly correlated across ages during the first year of life (Bornstein, Pecheaux, & Lecuyer, 1988; Byrne, Clark-Tousenard, Hondas, & Smith, 1985; Colombo, Mitchell, O'Brien, & Horowitz, 1987).

Second, individual differences in physiological measures have been shown to be related to recognition memory. Individual differences in measures of heart period variability, including respiratory sinus arrhythmia (RSA), are related to visual attention (Bornstein & Seuss, 2000; Porges, Arnold, & Forbes, 1973; Richards, 1987; Richards & Casey, 1992). RSA level is a stable individual difference that is significantly correlated across testing ages from 2 months to 15 months (Fracasso, Porges, Lamb, & Rosenberg, 1994; Izard, Porges, Simons, & Haynes, 1991; Richards, 1989, 1994; Stifter, Fox, & Porges, 1989). Individual differences in heart period variability and RSA have been interpreted as indexing an individual's level of parasympathetic cardiac control, which is related to capacity for attention and orienting (see Richards & Casey, 1992). Empirical results have provided support for these claims, with heart period variability positively correlated with novelty preference scores in a paired-comparison procedure (Linnemeyer & Porges, 1986).

Behavioral (i.e., look duration) and physiological (i.e., heart period variability) measures of attention may be independent markers of an infant's general developmental level and may not necessarily be causally related. However, there is reason to think that these individual differences may be related to recognition memory by some of the same common underlying processes. An important consideration in this regard concerns findings about the relation between infant looking and infant attention, which do not always coincide. This is evident because long-looking infants actually show less evidence of stimulus processing or recognition memory than short-looking infants (e.g., Colombo et al., 1995; Frick & Colombo, 1996). One would expect that if looking corresponded directly to attention, then the longer an infant looked at a stimulus, the more attention that would be allocated to the stimulus (and thus, better recognition memory for that stimulus that would be expected). Therefore, looking by itself may not provide an adequate measure of attention.

This finding is further supported by research on heart-rate-defined phases of attention. Researchers have postulated that phasic changes in heart rate correspond to different levels of attention (see Graham, Anthony, & Ziegler, 1983; Porges, 1980; Richards & Casey, 1991, 1992). Sustained, focused attention is characterized by a slowed heart rate, whereas attention termination is marked by heart rate returning to its prestimulus level. Infants are less distractible from stimuli when their heart rates correspond to the sustained attention phase than when they are in attention termination (Lansink & Richards, 1997; Richards, 1997b; Richards & Lansink, 1998). Importantly, changes in attention phases can occur during the same look to a stimulus; that is, a single look to a stimulus may be composed of multiple phases of attention. Thus, physiological measures may provide important information about attention that supplements what can be determined from looking alone. Individual differences in these phases of attention have also been discovered. Infants with higher baseline levels of heart period variability have been reported to show greater amounts of sustained visual attention, as defined by heart rate (Richards, 1987, 1997b). This, in turn, may affect recognition memory, as greater amounts of sustained attention would be expected to facilitate recognition memory.

Recent work has already indicated that heart-rate-defined attention phases are related to recognition memory. Richards (1997a) tested infants' recognition of visual stimuli presented for different lengths of time in a paired-comparison procedure. Infants showed a familiarity preference (suggesting incomplete or partial stimulus processing; see Hunter, Ames, & Koopman, 1983) for briefly presented (2.5 or 5.0 sec) stimuli but a novelty preference for stimuli presented for longer lengths of time (10.0 or 20.0 sec). However, in a second experiment, presentation of stimuli was coordinated with heart rate phases, such that the brief presentations coincided with experimentally defined phases of sustained attention or attention termination. Using this procedure, infants responded to the novel stimulus after 5.0 sec of exposure during sustained attention with a similar novelty preference level to that shown in a 20.0-sec exposure condition previously. The longer the infant spent in sustained attention (i.e., heart rate deceleration) during the familiarization phase, the higher the subsequent preference for the novel stimulus (Richards, 1997a). Thus, infants' recognition of stimuli in the paired-comparison procedure is affected by the amount of the familiarization period that is spent in sustained attention. Therefore, individual differences (e.g., in look duration and heart period variability) that are related to sustained attention are expected to be related to recognition memory.

The study presented here tested the effect of individual differences in look duration and heart period variability on recognition memory for briefly presented stimuli in a sample of full-term infants studied longitudinally from 14 to 26 weeks of age. Measures of heart period variability were collected from a 5-min baseline recording, and look durations to the dynamic stimuli presented in some of the experimental conditions were calculated. The recognition memory procedure generally replicated one that was used in a recent study (Richards, 1997a). The infants were presented with relatively brief (6.0 sec) stimuli at differing delays corresponding to different phases of attention. The familiar stimulus was presented either immediately, following 2.0 sec of looking to another stimulus, during sustained attention, or during attention termination. Infants with high heart period variability, short-looking infants, and older infants were expected to show greater looking to the novel stimulus during the test phase. The younger, long-looking infants and those with low heart period variability were expected to show less evidence of recognition memory for these relatively brief stimuli. However, those infants who typically show poor patterns of recognition memory in an unstructured stimulus presentation (e.g., long-looking infants or infants with low levels of heart period variability) may be aided by stimulus presentations occurring during sustained attention. The use of the longitudinal design allowed analysis of developmental changes and individual differences in these domains.

METHOD

Participants

Thirty-seven full-term infants (gestational age greater than 38 weeks, birthweight greater than 2500 g) were recruited from newspaper birth notices. These infants were tested longitudinally, at 14 ($N = 37$, 17 girls, 20 boys; $M = 97.5$ days, $SD = 7.7$), 20 ($N = 35$, 15 girls, 20 boys; $M = 141.4$ days, $SD = 5.0$), and 26 ($N = 33$, 15 girls, 18 boys; $M = 182.9$ days, $SD = 5.2$) weeks postnatal age. Two infants completed only the 14-week session, and 2 others completed only the 14- and 20-week sessions. These infants are not included in the final analyses. Infants had no medical complications and were in good health at the time of recording. The population from which the sample was drawn is mostly White and middle class. Participants were paid for their participation.

Apparatus and Stimuli

The infant was held in a parent's lap approximately 51 cm from the inner edge of two 49-cm (19-in.) color TV monitors. The center of each screen was 56 cm from the infant's eyes, and the far edge was 70 cm. The TVs subtended 88° visual angle, with one TV subtending 44° visual angle, and a visual angle of 48° from center to center of each monitor. A neutral color material covered the surrounding area. A video camera was positioned above the TVs, and in an adjacent room an observer judged infants' looks on a TV monitor. The session was recorded on videotape with a time code to synchronize physiological and experimental information.

The familiar and novel stimuli consisted of dynamic, black-and-white, computer-generated patterns (e.g., an alternating series of concentric squares, a flashing checkerboard pattern, a small box shape moving across a diamond). The stimulus display area subtended 32° visual angle. Several selected clips from a Sesame Street movie (*Follow That Bird*) were used to elicit heart rate changes. This Sesame Street stimulus was selected because it has been used successfully in past research to elicit the heart rate changes for the various experimental conditions (see Richards, 1997a, 1997b). Different video clips were used across the experimental session, and different clips were associated with different experimental conditions across ages. In past studies infants have successfully discriminated novel from familiar stimuli when those stimuli are viewed following these clips (see Richards, 1997a).

Procedure

Respiration and the electrocardiogram were recorded for a 5-min baseline period during which the infant sat quietly on the parent's lap on a couch. The parent was then seated in a chair with the child on his or her lap facing the TVs to begin the experimental procedure. The conditions differed in the manner in which the stimulus was presented in the familiarization phase (similar to the trial types used in Richards, 1997a). Each trial began with a 2.5-sec minimum prestimulus period. Four conditions (i.e., immediate, 2-sec, deceleration, and return of heart rate to prestimulus level) included a familiar stimulus presentation for 6.0 sec (i.e., exposure conditions), and two (i.e., 20-sec accumulation and no-exposure control) were control conditions. The four exposure conditions were theorized to correspond to different heart-rate-defined phases of attention, as detailed in Richards and Casey (1992). In all cases, the stimulus was presented until the infant had accumulated the necessary amount of looking at the stimulus. The infants received the six experimental conditions in random order, and each participant saw a different memory stimulus on each condition.

The conditions are presented in Table 1 (see also Richards, 1997a, for a figure with similar experimental conditions). The immediate condition is hypothesized to correspond to the stimulus orienting phase of attention, as the familiar stimulus is presented during the time in which the infant's attention has not yet become engaged with the stimulus (Richards & Casey, 1992). The 2-sec condition presents the familiar stimulus after the infant has already begun to attend to an interesting stimulus; thus, the infant is already in an engaged attentional state when the familiar stimulus is presented. The heart rate deceleration condition is analogous to the sustained attention phase, and the return of heart rate to prestimulus level condition is analogous to the attention termination phase. It is hypothesized that recognition memory will be superior in the experimental conditions corresponding to sustained attention than during attention termination or when attention is not yet engaged (i.e., immediate condition). The heart rate deceleration criterion was defined as five beats with interbeat intervals (IBIs) each longer than the median of the five prestimulus beats, and the criterion for return of heart rate to prestimulus level was defined as five beats with IBIs shorter than the median of the five prestimulus beats, following a heart rate deceleration (Richards, 1997a). Trials requiring heart rate decelerations were restarted if a heart rate deceleration did not occur within 10.0 sec of stimulus onset.

The test phase for recognition memory followed the familiarization phase and was the same for all conditions. In this phase, the stimulus to which the infant had previously been exposed (i.e., the familiar stimulus) was presented on one of the two TVs. As soon as the infant looked at it, the novel stimulus was presented on the adjacent TV. Thus, the infant's first look was always toward the familiar stimulus

TABLE 1
Experimental Conditions

Condition	*Description*
Immediate	Familiar stimulus presented immediately for 6.0 sec (no Sesame Street clip)
2-sec	Sesame Street clip for 2.0 sec → Familiar stimulus for 6.0 sec
Heart rate deceleration	Sesame Street clip through heart rate deceleration → Familiar stimulus for 6.0 sec
Return to prestimulus	Sesame Street clip through heart rate deceleration and return of heart rate to prestimulus level → Familiar stimulus for 6.0 sec
20-sec accumulation	Familiar stimulus presented immediately for 20.0 sec fixation (no Sesame Street clip; control condition)
No-exposure control	Sesame Street clip through heart rate deceleration and return of heart rate to prestimulus level (no familiar stimulus presented; control condition)

(except in the no-exposure control condition, in which both of the test phase stimuli were novel). This equated all infants for the stimulus to which they first looked during the paired-comparison trials. The two stimuli were presented for 10.0 sec of accumulated looking time on either stimulus, and then a second paired-comparison trial was presented in which the familiar stimulus was presented on the opposite TV, followed by the novel stimulus as soon as the familiar stimulus was fixated. This second paired-comparison trial also continued until 10.0 sec of looking time was accumulated to either stimulus.

Calculation of Novelty Preference Variables

The hypothesis that the four exposure conditions (i.e., immediate, 2-sec, heart rate deceleration, return of heart rate to prestimulus level) would result in different amounts of stimulus processing was tested by comparing look duration in the paired-comparison test phase for these four conditions with the control conditions of no exposure (which involved the paired comparison test phase only, with no familiar stimulus) or 20.0-sec accumulation. The first variable employed for analysis was the infants' first look duration from the test phase. The first look during the test phase of the no-exposure control trial was to a novel stimulus (because neither stimulus had been seen before). However, in the four exposure conditions, the first look was always to a familiar stimulus. Thus, recognition memory (i.e., a novelty preference) in the four exposure conditions would be shown by first look durations during the test phase that were significantly shorter than the first look duration for the no-exposure control condition.

The second variable analyzed to indicate recognition memory was the amount of looking at the novel stimulus from the test phase, which was compared to the 20.0-sec accumulation control condition. The 20.0-sec accumulation control was expected to result in novelty preferences in the test phase, based on previous research (Richards, 1997a). A novelty preference in the exposure conditions would be shown by look duration on the novel stimulus similar to that in the 20.0-sec accumulation condition.

This approach to calculation of novelty preference variables (also used in Richards, 1997a) differs from the standard approach of simply calculating the percentage of time that infants fixate the novel stimulus during the choice trials, relative to the total amount of fixation possible (i.e., Fagan, 1974; Rose, Feldman, & Wallace, 1988). The current method required the infant to fixate the familiar stimulus first during the test phase. At that point, the novel stimulus was presented, and the infant had to disengage from the familiar stimulus to view the novel stimulus. Presumably, the more thoroughly the familiar stimulus had been encoded, the more quickly the infant would have turned away from it and toward the novel stimulus.

Measurement and Quantification of Physiological Variables

The electrocardiogram (ECG) was recorded by placing silver–silver chloride electrodes on the infant's chest and was digitized at 1000 Hz (each msec) with a microcomputer running custom software. A computer algorithm identified the QRS complex in the ECG online, and IBI was defined as the duration between successive R-waves in the ECG. This evaluation was made online within 30 to 60 msec following the R-wave occurrence. For offline analyses, algorithms developed by Cheung (1981) and Berntson, Quigley, Jang, and Boysen (1990) were used to identify artifacts, along with visual inspection of unusual beats.

Respiration was measured with a pneumatic chest cuff (Grass Instruments) and was digitized online at 50 Hz (each 20 msec) during the baseline period. The peak and trough of the digitized recording, representing inspiration and expiration, were identified by computer algorithms. Artifacts were eliminated by viewing the respiration recording on computer displays for each identified breath. Respiration frequency was quantified to determine the modal frequency for RSA quantification.

Individual differences in heart period variability in past research have been determined by separating high- and low-variability groups with a single variable, such as a band-pass filter measure ("V"; Porges, 1992) or a spectral analysis measure (Richards, 1994). However, parasympathetic cardiac control involves both a lowering of mean heart rate and an increase in RSA, and these two functions of parasympathetic control are partially independent. One approach to developing a measure of parasympathetic cardiac control, therefore, would be to use both mean heart rate and RSA in some linear combination (e.g., multiple regression; Grossman & Kollai, 1993; Kollai & Mizsei, 1990). Thus, four variables were computed from the baseline recording: IBI average, standard deviation of the IBI values, a time-domain quantification of RSA, and a frequency-domain quantification of RSA (see Richards, 1997b, for a detailed explanation of these variables). Each variable was calculated separately from the 5 baseline min, and an average of the five calculations was taken. The IBIs were proportionally assigned to 100-msec intervals to achieve adequate resolution of the frequency-domain RSA measure.

Richards (1997b) performed a principal component analysis on these IBI and RSA variables with a large cross-sectional sample of infants (N = 155) to derive a summary measure of individual differences in heart period variability. Because our study involved a smaller number of infants studied longitudinally, the loadings for these variables from the first principal component in that previous analysis (reported in Table 3 of Richards, 1997b) were used in this study to compute principal component scores for each infant. In that previous study, the principal components variable was more sensitive to individual differences in attention in some analyses than were other variables (see Richards, 1997b, footnote 3, p. 672).

Look Direction

A single observer in an adjacent room judged the look direction of the infant on a TV monitor during the experiment. Two observers later judged look direction offline via a videotaped recording. Each look was judged as looking at the right TV, looking at the left TV, or looking away. Looking times were computed based on a millisecond time code recorded on the videotapes. The data for the analyses came from the ratings of only one of the observers.

Interrater reliabilities of look duration judgments were computed between the ratings of the two observers. The average absolute difference for the judgments of the length of the first look toward the familiar stimulus in the paired-comparison phase was 0.396 sec (N = 696, SD = 0.908, Mdn = 0.127 sec, 90 P = 0.934 sec), and for total looking toward the novel stimulus in the first 10 sec of the paired comparison was 0.506 sec (N = 696, SD = 0.731, Mdn = 0.274 sec, 90 P = 1.28 sec). The overlap agreement for the duration of looking and judgments of looking at the familiar or novel stimulus was examined for the two observers. The total time in all of the trials was 365 min. The overlap between the two observers for looking toward the stimuli averaged across trials was 0.90 (SD = .130, Mdn = 0.950, 90 P = 1.0, Cohen's κ = .585). This shows a moderate reliability (Landis & Koch, 1977) for the observations, with the level of Cohen's κ due to the relatively high frequency of looking toward the stimuli (Hunter & Koopman, 1990). Given that the observers judged the infant to be looking toward the stimuli, the overlap time for agreement that looking was directed to the novel or familiar stimulus was 0.91 (SD = 0.113, Mdn = 0.952, 90 P = 1.0, Cohen's κ = .777).

RESULTS

Baseline Physiological Measures

Table 2 presents the means for the variables used to classify infants according to individual differences in heart period variability. A one-way MANOVA was performed to examine overall changes with age in these measures of heart period variability. There was a statistically reliable age effect, Wilks's Λ = .83, $F(8, 196)$ = 2.46, p = .015. Consistent with previous studies (Richards, 1997b), IBI increased (i.e., heart rate declined) with age, and RSA increased with age.

As in previous research (Richards, 1997b), all measures of heart period variability were highly correlated; in this study, these intercorrelations ranged from .59 to .92. Infants were separated into high and low heart period variability groups by use of a median split within ages on the principal component score. The medians were –.654, .022, and .674, respectively, for the three age groups. For the overall classification of infants as high or low heart period variability, the average of each infant's

TABLE 2
Developmental Changes in Physiological and Looking Measures

	Value at Testing Age (Weeks)			
Parameter	*14*	*20*	*26*	*p*
Average IBI length (msec)	398.9	415.0	425.0	.006*
SD of IBI	27.9	27.7	30.0	.356
Band-pass filter RSA estimate	3.35	4.06	4.48	.019*
Spectral analysis RSA estimate	1.85	2.29	2.38	.049*
Principal component score	–.586	.070	.531	.025*
Peak fixation duration, no-exposure control (sec)	15.6	11.5	8.8	.024*
Peak fixation duration, 20-sec control (sec)	13.9	8.2	8.7	.001**

Note. IBI = interbeat interval; RSA = respiratory sinus arrhythmia.
$^*p < .05$. $^{**}p < .01$.

three principal component scores (from the three testing ages) was computed, and then a median split was performed on this variable. The overall median principal component score was –0.098. The high and low heart period variability groups differed significantly on their principal components score, $F(1, 98) = 78.14$, $p < .001$.

Look Duration Variables

Infants' longest looks during the two control conditions were examined to estimate individual differences in look duration. These two conditions were selected because they both provided an extended period in which a stimulus was presented (i.e., either for a full 20.0 sec of familiarization to one of the dynamic geometric patterns in the 20.0-sec control condition or through a heart rate deceleration and acceleration while watching a clip from the Sesame Street movie in the no-exposure control condition). As expected, there was a decrease across the three testing ages in the length of the longest look in both conditions (see Table 2). Next, we examined the correlations between these two measures at each age and the correlation of each measure with itself across the testing ages. The longest looks in the two control conditions were not significantly correlated with each other within a testing age (*r*'s were .19, .06, and –.25, respectively, for the three age groups, all *ns*), and the longest looks from each control condition at a given testing age were not significantly correlated with the subsequent testing age (correlations ranged from –.12 to .15, all *ns*). This finding indicates that the look duration measure obtained in this experimental procedure was not stable within a testing age (i.e., between the two control conditions) or across testing ages (i.e., each control condition across age). Thus, infants could not reliably be classified as long or short looking across testing ages, and this grouping variable was not included in further analyses.

The longest look durations from the two control conditions were examined in relation to the baseline physiological measures taken at each age. There were no significant correlations between the looking measures and the baseline physiological measures for the 14-week-old infants. At 20 and 26 weeks of age, however, several of the measures of heart period variability had significant positive correlations with look duration, but only for the no-exposure control trial. In particular, the principal components score at 20 and 26 weeks was positively correlated with the longest look duration from the no-exposure control trial ($r = .36$ and .44, respectively, $p < .05$). Infants with higher baseline levels of heart period variability looked longer at the clip from the Sesame Street movie.

The longest looks from the two control trials were analyzed with an age (3: 14, 20, 26 weeks) × heart period variability (2: low, high) analysis of variance (ANOVA; looking measures were log-transformed in ANOVAs). There was a main effect of age on the longest look from the no-exposure condition, $F(2, 89) = 3.91$, $p = .0235$, and the 20.0-sec accumulation control trial, $F(2, 94) = 11.50$, $p < .0001$ (see Table 2). There were no main effects or interactions involving the heart period variability factor. However, planned analyses of these variables separated by age showed that the longest look duration for the no-exposure control trials was significantly shorter for the 26-week-old infants with low levels of heart period variability than for the 26-week-old infants with high heart period variability (i.e., 6.56 sec for low heart period variability infants and 11.32 for high heart period variability infants), $F(1, 27) = 4.24$, $p < .05$.

In summary, these analyses indicated that infants could not be reliably classified as long looking or short looking using the current experimental procedure. However, look duration variables were positively correlated with the baseline physiological measures, particularly at the older ages. Older infants with higher baseline levels of heart period variability tended to look longer during the no-exposure control condition.

Recognition Memory During Experimental Trials

Analyses with first look duration. First, analyses were conducted on infants' first look duration, compared to the no-exposure control trial. A novelty preference would be shown by shorter first look duration during the test phase for the exposure conditions than first-look duration for the no-exposure control, in which both stimuli were novel. Thus, first-look duration was analyzed with an age (3) × heart period variability (2: low, high) × exposure condition (5: immediate, 2.0 sec, heart rate deceleration, return of heart rate to prestimulus level, no-exposure control) ANOVA.

There was a statistically reliable main effect of testing age on the first look, $F(2, 96) = 36.15$, $p < .0001$. The first looks were longest for the youngest infants, at an intermediate level for the 20-week-old infants, and the shortest for the oldest infants (see Table 3). Figure 1 shows the first look durations broken down by theoretically similar experimental conditions. Specifically, the immediate and return conditions were combined, in which attention is theorized not to be engaged, and the 2.0-sec and deceleration conditions were combined, in which attention is theorized to be engaged.

The overall main effect of exposure condition was not significant, $F(4, 96) = 1.15$, *ns,* nor were there, overall, any statistically reliable interactions between exposure condition and age or heart period variability. However, several key comparisons between means were conducted based on the experimental hypotheses and results from Richards (1997b). It was expected that the 14-week-old infants may not show evidence of recognition memory for these brief stimuli and so may not be affected by the trial type, whereas the older two ages may be. As shown in Figure 1, the first looks for the 14-week-olds were similar in all conditions, whereas first looks for the older infants did differ across experimental conditions. Specifically, the first look duration for the 20- and 26-week-olds in

TABLE 3
Developmental Changes in Novelty Preference Measures

	Value at Testing Age (Weeks)		
Measure	*14*	*20*	*26*
First look duration (sec) to familiar stimulus			
Immediate	4.12	2.36	1.08
2-sec	4.42	1.74	1.33
Heart rate deceleration	3.93	1.46	1.30
Return to prestimulus	4.29	2.21	1.86
No-exposure control	3.99	1.91	2.57
20-sec control	4.09	2.03	1.40
Average, all conditions	4.06	1.99	1.60
Percentage looking at novel stimulus (first 10 sec)			
Immediate	43.95	53.76	51.45
2-sec	41.29	52.88	53.74
Heart rate deceleration	40.15	48.69	54.61
Return to prestimulus	36.03	36.51	39.75
20-sec control	39.38	54.35	61.97
Average, all conditions	38.97	48.82	50.94
Percentage looking at novel stimulus (entire 20 sec)			
Immediate	41.24	49.22	52.32
2-sec	39.49	50.34	50.81
Heart rate deceleration	40.22	46.99	53.79
Return to prestimulus	37.28	42.84	42.43
20-sec control	38.54	52.97	54.62
Average, all conditions	39.43	48.04	51.43

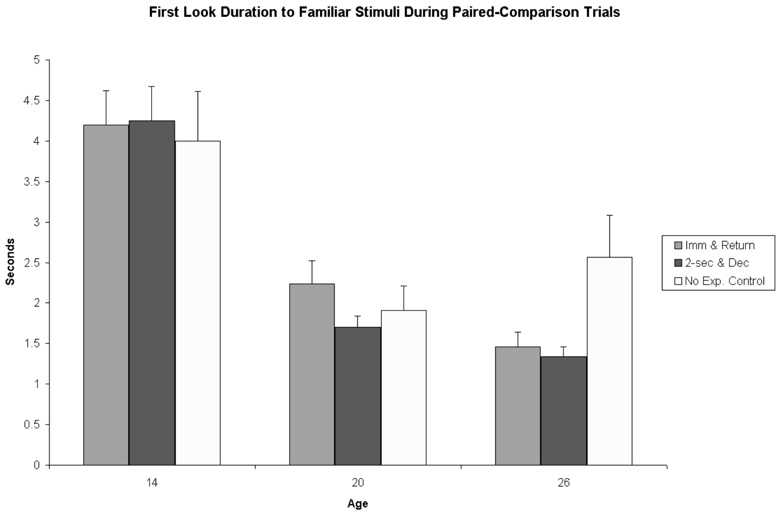

FIGURE 1 First look duration (to the familiar stimulus) during the paired-comparison trials, presented separately by age and experimental condition. Fourteen-week-olds show little differentiation between conditions, but the older two age groups show shorter first looks (i.e., greater novelty preference) in the experimental conditions relative to the control condition. Error bars represent *SEM.*

the 2.0-sec and heart rate deceleration trials (i.e., the attention conditions) was significantly shorter than the first looks in the no-exposure control trial, $F(1, 63) = 4.13$, $p = .046$. Thus, in the two older age groups, as Figure 1 and Table 3 show, there was evidence that presentation of brief stimuli during heart-rate-defined phases of attention facilitated recognition memory. However, these two older age groups did not show shorter first looks in the immediate and return of heart rate to prestimulus level conditions than the infants in the no-exposure condition, $F(1, 63) = .52$, *ns.*

There was also a statistically significant effect of heart period variability on the first look duration, $F(1, 96) = 4.86$, $p < .05$. The first looks of the high heart period variability infants were shorter than the first looks of the low heart period variability infants, indicating shorter looks to the familiar stimulus (i.e., higher novelty preference) in the high heart period variability infants. This is illustrated in Figure 2, which shows that in particular, the high heart period variability infants showed significantly shorter first looks in the two attention conditions than the low heart period variability infants.

In summary, as demonstrated in Figure 1, the first look durations for the 14-week-old infants were similar for all conditions. The first look durations for

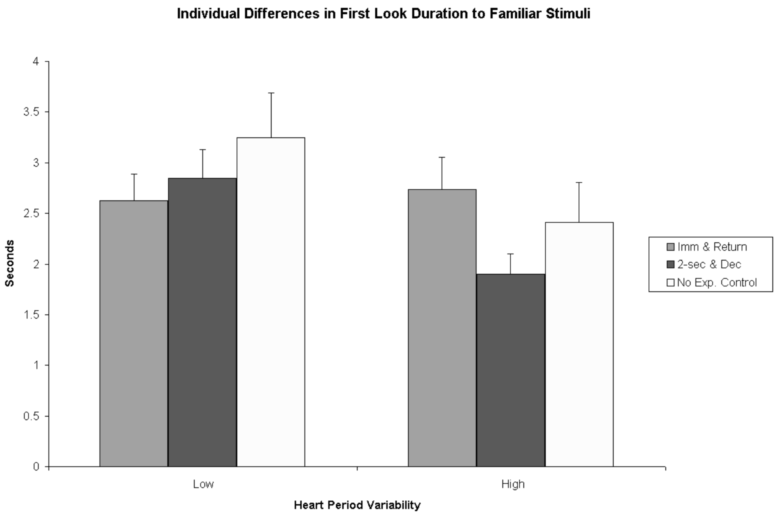

FIGURE 2 First look duration to the familiar stimulus during paired-comparison trials, shown separately for the high and low heart period variability infants. Infants with high heart period variability showed shorter first looks (i.e., greater novelty preference), particularly in the experimental conditions thought to reflect sustained attention. Error bars represent *SEM.*

both 20- and 26-week-old infants were less in the 2.0-sec and heart rate deceleration trials than in the no-exposure control condition. Figure 2 also indicates that high heart period variability infants showed shorter first looks than did the low heart period variability infants. Summed across ages and experimental conditions, older infants and infants with high heart period variability showed greater evidence of recognition memory for these brief stimuli.

Analyses with novel look duration variables. The percentage of time looking at the novel stimulus is very similar for the first 10-sec test trial as for the entire 20-sec test phase (see Table 3). Analyses are reported here for looking to the novel stimuli during the first 10 sec of the paired-comparison test phase because this measure better represented the infant's initial processing of the briefly presented stimuli; results are similar if novel look duration from the entire 20-sec test phase is analyzed. Novel look duration from the exposure conditions was compared to length of looking at the novel stimulus during the test phase of the 20.0-sec accumulation condition, which was theorized to result in thorough processing of the familiar stimulus (see Richards, 1997b). The duration of novel stimulus looking on these trials was analyzed with an age (3) × heart period variability (2) × exposure condition (5: immediate, 2.0-sec, heart rate deceleration, return of heart rate to prestimulus level, 20.0-sec accumulation) ANOVA.

There was a statistically reliable main effect of testing age on the novel look duration, $F(2, 96) = 33.20$, $p < .0001$. This effect was as expected; novel look duration was shortest for the 14-week-olds (3.897 sec), at an intermediate level for the 20-week-old infants (4.88 sec), and the longest for the 26-week-old infants (5.09 sec; see Table 3 and Figure 3). This finding indicates increasing recognition memory in the paired-comparison test over this age range.

As with the first look duration variable, the type of exposure condition did not significantly affect the duration of novel looking when all three testing ages were combined, $F(4, 96) = 0.71$, *ns*. However, for the 20- and 26-week-old infants, there was a statistically significant effect of exposure condition, $F(4, 96) = 6.72$, $p = .015$. The 14-week-old infants showed little difference across exposure conditions in the time spent looking at the novel stimulus (see Figure 3). For the older two ages, however, the time spent looking at the novel stimulus in the paired-comparison phase for the 2.0-sec and heart rate deceleration trials (i.e., attention conditions) was not significantly different from the 20.0-sec accumulation condition (see Figure 3). On the other hand, the time spent looking at the novel stimulus in the paired-comparison phase for the immediate and return of heart rate to

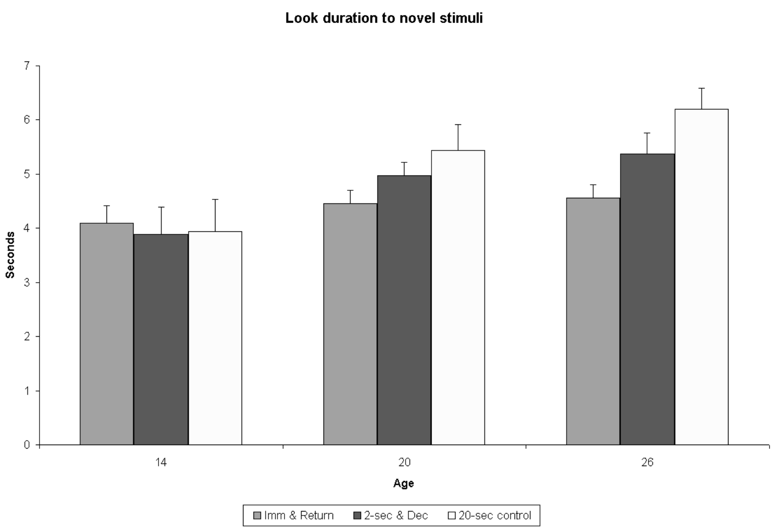

FIGURE 3 Look duration to novel stimuli during the first 10-sec test trial, presented separately for the three age groups and broken down by experimental conditions. Looking to the novel stimulus increased with age, particularly in conditions in which recognition memory was expected. Error bars represent *SEM*.

prestimulus level conditions (i.e., no attention conditions)[1] was significantly less than during the 20.0-sec accumulation conditions (see Figure 3). The two oldest ages showed novelty preference (i.e., recognition memory) after 6.0 sec of exposure in the conditions corresponding to heart-rate-defined phases of attention but not in the experimental conditions hypothesized to reflect a lack of attention. There were no main effects or interactions involving the heart period variability measure for this variable.

In summary, novel look durations are presented by age and experimental condition in Figure 3. The 14-week-old infants showed little evidence of recognition memory in any of the heart-rate-defined experimental conditions. The older two age groups, however, showed greater looking to the novel stimulus during attention conditions than nonattention conditions.

DISCUSSION

Age and Experimental Effects on Recognition Memory

Twenty- and 26-week-old infants showed greater evidence of recognition memory for these briefly presented visual stimuli than did 14-week-old infants. The older two age groups, overall, had greater looking to the novel stimulus during the paired-comparison trials and also made shorter first looks to the familiar stimulus during the paired-comparison trials. These findings are consistent with the interpretation that infants become more efficient at stimulus processing and require less familiarization time before demonstrating significant novelty preferences with age (see also Fagan, 1974; Rose et al., 1988). Infants also show more rapid disengagement of looking from visual targets with age, and thus the current results could be attributed partially to infants' increasing ability to shift attention rapidly between targets and locate novel visual stimuli more rapidly with age (see Frick, Colombo, & Saxon, 1999; Hood & Atkinson, 1993; Johnson, Posner, & Rothbart, 1991; Richards, 1987, 1997b). This finding of age differences also replicates the age effects reported in Richards (1997a) for recognition of briefly presented visual stimuli.

However, the relation between age and recognition memory was mediated by the effects of the experimental manipulations. The 14-week-old infants showed no differentiation in their performance among the various conditions and little evidence of recognition memory for any of these briefly presented stimuli. Although

[1]The immediate and return of heart rate to prestimulus level conditions were combined to represent inattention conditions because of a priori theoretical predictions. Table 3 shows that the immediate condition resulted in higher levels of looking at the novel stimulus than did the return condition. However, both conditions (when analyzed separately) were different from the 20.0-sec control condition.

14-week-olds exhibited significant novelty preferences in past work (e.g., Cooper, 1990; Frick, Colombo, & Allen, 2000), the brief familiarization employed in this procedure may have not provided enough time for sufficient stimulus processing for this age group (Richards, 1997a). An alternate interpretation of the performance of the 14-week-olds is that they may have been processing the information in these rather complex, moving stimuli differently than the older infants. Specifically, they may have been processing the stimuli in a more piecemeal fashion, engaging in analysis of the local stimulus components rather than the global shape or structure of the stimuli (see Bronson, 1991; Hainline & Lemerise, 1982). If that were the case, the younger infants would have more information to process than the older ones. The younger infants would take longer initial looks and would need longer exposures to remember the stimuli, not because they have poorer memories, but because they have more information in the stimuli to remember (see Cohen, 1998).[2] However, that 14-week-olds' performance was relatively insensitive to the heart rate experimental manipulations (relative to the 20- and 26-week-olds) suggests that there may be important developmental changes in attention that affect recognition memory performance across these ages.

The older two age groups showed shorter first looks on the familiar stimulus in the conditions expected to result in greater recognition memory (i.e., 2.0-sec and deceleration). In addition, infants in the older two age groups showed greater looking at the novel stimulus in the 2.0-sec and deceleration conditions but not in the immediate or return of heart rate to prestimulus level conditions. The heart-rate-defined experimental manipulations led to significantly different amounts of recognition memory in the theoretically predicted directions in the older two age groups; this finding provides theoretical support for the hypothesis that heart-rate-defined attention phases are associated with focused attention to visual stimuli (Richards & Casey, 1992).

These results indicate that 20- and 26-week-old infants are capable of demonstrating recognition memory for stimuli following a relatively brief stimulus exposure if that exposure occurs while the infant is in an attentive state (see Richards, 1997a). Experimental paradigms that manipulate length of familiarization as an indication of processing time required for recognition may overestimate the time required for infants to process visual stimuli (see also Fagan, 1974). However, a further implication is that those studies that have found differences in the familiarization time required for recognition memory by infants of different ages and different attentional statuses (e.g., Colombo et al., 1995; Colombo et al., 1991; Rose, 1983) may have tapped into differences in the time infants in these different groups spent in sustained attention during familiarization. This possibility deserves further consideration.

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[2]We thank a reviewer for pointing out this valid alternate interpretation.

Individual Differences Results

Look duration measures. A number of analyses were conducted to examine the relation between individual differences in look duration and recognition memory. One difference between the current results and previous findings is that the look duration measures were not stable either across task or across age. This finding stands in apparent contradiction to previous studies that have reported within-session stability in look duration measures (e.g., Bornstein & Benasich, 1986; Cooper, 1990; Frick & Colombo, 1996; Frick et al., 1999; Rose, Slater, & Perry, 1986) as well as cross-age stability in look duration (Colombo et al., 1987; Mayes & Kessen, 1989).

One possibility for why the look duration measures were not stable in this study is that the current experimental paradigm may have contributed to more variable looking responses. Infants were presented with six experimental conditions in random order; for example, the no-exposure control condition may have occurred first for an infant at 14 weeks but elsewhere in the session at 20 or 26 weeks. It is possible that differences in order of conditions contributed to a lessening of individual differences in look duration. Most previous studies that have reported stability in look duration measures have obtained those measures at the beginning of the experimental session. The possibility that individual differences in look duration are stronger or more stable in the infants' initial response during the experimental session deserves further empirical examination.

A second possibility is that stimulus characteristics may have influenced the pattern of results. Although look duration measures were not correlated with each other, they were significantly positively correlated with several of the physiological measures, particularly in the older infants. One interpretation of these findings is that look duration to changing, interesting visual stimuli (e.g., a clip from a Sesame Street movie) is more strongly related to physiological indicators of attention than is look duration to static, unchanging stimuli. This interpretation is bolstered by the finding that the correlations between look duration and baseline physiological measures were significant only for the no-exposure control condition (which involved presentation of a clip from the Sesame Street movie) and not for the 20.0-sec accumulation condition (which involved presentation of a geometric pattern that was more analogous to a habituation-type stimulus, although it was dynamic). Static, unchanging stimuli have most often been used in habituation paradigms that have led to the previous findings of stability in measures of individual differences in look duration. This finding raises the possibility of a greater degree of stimulus specificity for the relation between physiological and behavioral measures of attention than has previously been hypothesized.

It may be that the classification of infants as short looking or long looking (e.g., Colombo & Mitchell, 1990) may be appropriate only with particular types of visual stimuli. That is, individual differences in look duration may only be theoretically meaningful and empirically consistent when infants are presented with relatively unengaging, repetitive stimuli, to which they can habituate. Look duration to unchanging, habituation-type stimuli has been shown to be moderately stable both within and across ages (Colombo, 1993). It may be that look duration with static, unchanging stimuli (as are used in habituation studies) is more reflective of individual differences in speed of stimulus processing than is look duration to dynamic, changing stimuli, as in this study. It is interesting to note that infants' longest look durations became progressively shorter across ages (see Table 2), but that these longest look durations were positively correlated with the physiological measures typically interpreted as indicating attentional capacity and that increase with age.

Baseline physiological measures and recognition memory. Individual differences in the baseline physiological measures also were related to some aspects of recognition memory performance (see also Linnemeyer & Porges, 1986). Infants with low baseline levels of heart period variability had longer initial looks to the familiar stimulus during the paired-comparison trials relative to high heart period variability infants (see Figure 2). This difference was especially evident in the conditions that were expected to result in superior stimulus processing (i.e., 2.0-sec and deceleration condition combined). High heart period variability infants showed more rapid disengagement from the familiar stimulus during the paired-comparison trials, suggestive of more rapid recognition of it as familiar, and an enhanced novelty preference. One characteristic of the high heart period variability infants may be more rapid processing or recognition of familiar items, resulting in a larger proportion of time spent looking at the novel stimulus.

The lack of any main effects or interactions of the heart period variability measure on infants' duration of looking at the novel stimulus summed across the entire test trial, however, indicates that these individual differences may be more evident in infants' initial responses during the test phase. Alternately, it may be that the current experimental procedure, which required infants to fixate the familiar stimulus first, obscured individual differences in novelty preference related to heart period variability; a traditional paradigm in which the novel and familiar stimulus are presented simultaneously may show greater differences between heart period variability groups (see Linnemeyer & Porges, 1986).

Some hypotheses regarding individual differences in baseline physiological measures were not supported. High heart period variability infants did show greater evidence of recognition memory, as expected. However, it was also predicted that low heart period variability infants may benefit from stimulus presentations occurring during sustained attention (i.e., 2.0-sec and deceleration experimental conditions) and be more likely to show recognition memory in these attention conditions than in others. However, the results did not support this prediction. It may be that this specific experimental procedure is more difficult than a standard familiarization–novelty paired-comparison paradigm and thus resulted in floor effects on infants' performance that made individual difference results more limited.

Overall, individual differences in physiological measures and look duration were related to recognition memory performance in more specific ways than originally hypothesized. Nevertheless, infants with higher levels of heart period variability showed more rapid disengagement from the familiar stimulus during the test phase, perhaps indicating more rapid recognition of it as familiar. Further, these results provide evidence that stimulus and procedural factors may be more relevant in the study of infant visual attention than has previously been proposed. Future work should continue to examine the methodological and theoretical importance of these issues and further evaluate the mechanisms by which individual differences in behavioral and physiological measures of attention are related to early cognitive development (Colombo & Frick, 1999).

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REFERENCES

Berntson, G. G., Quigley, K. S., Jang, J. F., & Boysen, S. T. (1990). An approach to artifact identification. *Psychophysiology, 27,* 586–598.

Bornstein, M. H., & Benasich, A. A. (1986). Infant habituation: Assessments of individual differences and short-term reliability at five months. *Child Development, 57,* 87–99.

Bornstein, M. H., Pecheaux, M. G., & Lecuyer, R. (1988). Visual habituation in human infants: Development and rearing circumstances. *Psychological Research, 50,* 130–133.

Bornstein, M. H., & Seuss, P. E. (2000). Physiological self-regulation and information processing in infancy: Cardiac vagal tone and habituation. *Child Development, 71,* 273–287.

Bronson, G. W. (1991). Infant differences in rate of visual encoding. *Child Development, 62,* 44–54.

Byrne, J. M., Clark-Tousenard, M. E., Hondas, B. J., & Smith, I. M. (1985, April). *Stability of individual differences in infant visual attention.* Paper presented at the Biennial Meetings of the Society for Research in Child Development, Toronto, Canada.

Cheung, M. N. (1981). Detection and recovery from errors in cardiac inter-beat intervals. *Psychophysiology, 18,* 341–346.

Cohen, L. B. (1998). An information-processing approach to infant perception and cognition. In F. Simion & G. Butterworth (Eds.), *The development of sensory, motor, and cognitive capacities in early infancy* (pp. 277–300). East Sussex, England: Psychology Press.

Colombo, J. (1993). *Infant cognition: Predicting later intellectual functioning.* Newbury Park, CA: Sage.

Colombo, J., Freeseman, L. J., Coldren, J. T., & Frick, J. E. (1995). Individual differences in infant fixation duration: Dominance of global versus local stimulus properties. *Cognitive Development, 10,* 271–285.

Colombo, J., & Frick, J. E. (1999). Recent advances and issues in the study of preverbal intelligence. In M. Anderson (Ed.), *The development of intelligence* (pp. 43–71). Philadelphia: Psychology Press.

Colombo, J., & Mitchell, D. W. (1990). Individual differences in early visual attention: Fixation time and cognitive processing. In J. Colombo & J. Fagen (Eds.), *Individual differences in infancy* (pp. 193–228). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Colombo, J., Mitchell, D. W., Coldren, J. T., & Freeseman, L. J. (1991). Individual differences in infant visual attention: Are short lookers faster processors or feature processors? *Child Development, 62,* 1247–1257.

Colombo, J., Mitchell, D. W., O'Brien, M., & Horowitz, F. D. (1987). Stability of visual habituation during the first year of life. *Child Development, 58,* 474–487.

Cooper, R. P. (1990, April). *Novelty preference testing and visual habituation procedures: Reliabilities and relationships between measures at 3 months of age*. Paper presented at the International Conference on Infant Studies, Montreal, Canada.

Fagan, J. F. (1974). Infant recognition memory: The effects of length of familiarization and type of discrimination task. *Child Development, 59,* 1198–1210.

Fagan, J. F. (1984). The intelligent infant: Theoretical implications. *Intelligence, 8,* 1–9.

Fracasso, M. P., Porges, S. W., Lamb, M. E., & Rosenberg, A. A. (1994). Cardiac activity in infancy: Reliability and stability of individual differences. *Infant Behavior and Development, 17,* 277–284.

Frick, J. E., & Colombo, J. (1996). Individual differences in infant visual attention: Recognition of degraded visual forms by four-month-olds. *Child Development, 67,* 188–204.

Frick, J. E., Colombo, J., & Allen, J. R. (2000). Temporal sequence of global-local processing in 3-month-old infants. *Infancy, 1,* 375–386.

Frick, J. E., Colombo, J., & Saxon, T. F. (1999). Individual and developmental differences in disengagement of fixation in early infancy. *Child Development, 70,* 537–548.

Graham, F. K., Anthony, B. J., & Ziegler, B. L. (1983). The orienting response and developmental processes. In D. Siddle (Ed.), *Orienting and habituation: Perspectives in human research* (pp. 371–430). Sussex, England: Wiley.

Grossman, P., & Kollai, M. (1993). Respiratory sinus arrhythmia, cardiac vagal tone, and respiration: Within- and between-individual relations. *Psychophysiology, 30,* 486–495.

Hainline, L., & Lemerise, E. (1982). Infants' scanning of geometric forms varying in size. *Journal of Experimental Child Psychology, 33,* 235–256.

Hood, B. M., & Atkinson, J. (1993). Disengaging visual attention in the infant and adult. *Infant Behavior and Development, 16,* 405–422.

Hunter, M. A., Ames, E. W., & Koopman, R. (1983). Effects of stimulus complexity and familiarization time on infant preferences for novel and familiar stimuli. *Developmental Psychology, 19,* 338–352.

Hunter, M. A., & Koopman, R. (1990). Interobserver agreement and reliability of infant visual fixation data. *Infant Behavior and Development, 13,* 109–116.

Izard, C. E., Porges, S. W., Simons, R. F., & Haynes, O. M. (1991). Infant cardiac activity: Developmental changes and relations with attachment. *Developmental Psychology, 27,* 432–439.

Jankowski, J. J., & Rose, S. A. (1997). The distribution of visual attention in infants. *Journal of Experimental Child Psychology, 65,* 127–140.

Johnson, M. H., Posner, M. I., & Rothbart, M. K. (1991). Components of visual orienting in early infancy: Contingency learning, anticipatory looking, and disengaging. *Journal of Cognitive Neuroscience, 3,* 335–344.

Kollai, M., & Mizsei, G. (1990). Respiratory sinus arrhythmia is a limited measure of parasympathetic control in man. *Journal of Physiology, 222,* 1–15.

Landis, J. R., & Koch, G. G. (1977). An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics, 33,* 363–374.

Lansink, J. M., & Richards, J. E. (1997). Heart rate and behavioral measures of attention in six-, nine-, and twelve-month-old infants during object exploration. *Child Development, 68,* 610–620.

Linnemeyer, S. A., & Porges, S. W. (1986). Recognition memory and cardiac vagal tone in 6-month-old infants. *Infant Behavior and Development, 9,* 43–56.

Mayes, L. C., & Kessen, W. (1989). Maturational changes in measures of habituation. *Infant Behavior and Development, 12,* 437–450.

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

Porges, S. W. (1992). Autonomic regulation and attention. In B. A. Campbell, H. Hayne, & R. Richardson (Eds.), *Attention and information processing in infants and adults* (pp. 201– 223). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

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

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

Richards, J. E. (1989). Sustained visual attention in 8-week-old infants. *Infant Behavior and Development, 12,* 425–436.

Richards, J. E. (1994). Baseline respiratory sinus arrhythmia and heart rate responses during sustained visual attention in preterm infants from 3 to 6 months of age. *Psychophysiology, 31,* 235–243.

Richards, J. E. (1997a). Effects of attention on infants' preference for briefly exposed visual stimuli in the paired-comparison recognition-memory paradigm. *Developmental Psychology, 33,* 22–31.

Richards, J. E. (1997b). Peripheral stimulus localization by infants: Attention, age, and individual differences in heart rate variability. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 667–680.

Richards, J. E., & Casey, B. J. (1991). Heart rate defined phases of infant visual information processing. *Psychophysiology, 28,* 43–53.

Richards, J. E., & Casey, B. J. (1992). Development of sustained visual attention in the human infant. In B. A. Campbell, H. Hayne, & R. Richardson (Eds.), *Attention and information processing in infants and adults* (pp. 30–60). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Richards, J. E., & Lansink, J. M. (1998). Distractibility during visual fixation in young infants: The selectivity of attention. In C. Rovee-Collier & L. Lipsitt (Eds.), *Advances in infancy research* (Vol. 13, pp. 407–444). Greenwich, CT: Ablex.

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

Rose, S. A., & Feldman, J. F. (1997). Memory and speed: Their role in the relation of infant information processing to later IQ. *Child Development, 68,* 630–641.

Rose, S. A., Feldman, J. F., & Wallace, I. (1988). Individual differences in infant information processing: Reliability, stability, and prediction. *Child Development, 59,* 1177–1197.

Rose, D., Slater, A., & Perry, H. (1986). Prediction of childhood intelligence from habituation in early infancy. *Intelligence, 10,* 251–263.

Stifter, C. A., Fox, N. A., & Porges, S. W. (1989). Facial expressivity and vagal tone in 5- and 10-month-old infants. *Infant Behavior and Development, 12,* 127–137.