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Development of Sustained Visual Attention in the Human Infant

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Many investigators have posited that infant attention consists of multiple components or processes (Cohen, 1972, 1973; Richards, 1987; Ruff, 1986a). The components of infant attention occur sequentially. Cognitive activity differs during these components, and during each component the infant processes stimulus information differently. The idea of attention phases, or components of attention, occurs in the literature on adult cognition. Many researchers examining adult cognition (e.g., Posner & Boies, 1971; Posner & Cohen, 1982; Robinson & Peterson, 1986) have postulated distinct components of attention in adult cognitive activity.

The theoretical models of attention components posit that attention phases may be distinguished by their utilization of cognitive processing resources. Behavioral measures or physiological arousal can be used to assess resource utilization. An example of a behavioral measure is the "dual-task" procedure (see Siddle & Spinks, this volume). Performance on a "primary" task and a "secondary" task (often a probe) may require the same processing resources. Allocating resources to either the primary or secondary task reduces the level of resources available for the other task. The degradation of performance on the other task is a measure of the level of resource allocation to the original task. Active cognitive processing also affects physiological systems. The amount of cognitive resources allocated is thought to be proportional to the extent of physiological responses (Jennings, 1986; Kahneman, 1973). Many

physiological systems (e.g., heart rate, pupil dilation, respiration, skin conductance response) correlate with resource allocation (Jennings, 1986).

This chapter reviews research showing that infant attention consists of multiple components, emphasizing individual and developmental differences in sustained attention. Two concerns are emphasized. First, behavioral measures can be used to distinguish components of infant attention. Second, heart rate (HR) changes during visual fixation closely parallel the behavioral measures. The distinction of attention components in infants relies on a multi-operational definition using both behavior and HR.

A MODEL OF HEART RATE DEFINED ATTENTION PHASES IN INFANTS

Infant HR has been hypothesized to index at least four information-processing phases (Graham, 1979; Graham, Anthony, & Ziegler, 1983; Porges, 1976, 1980; Richards, 1988a). These phases are the automatic interrupt, stimulus orienting, sustained attention, and attention termination. Each of the phases has a unique type of fixation-linked HR change that may be used to index which attention phase is occurring. Figure 2.1 schematically depicts the HR changes occurring during the latter three phases. Also included in Fig. 2.1 are "pre-attention" and "pre-attention termination" periods. The pre-attention period is simply the time before the presentation of the visual

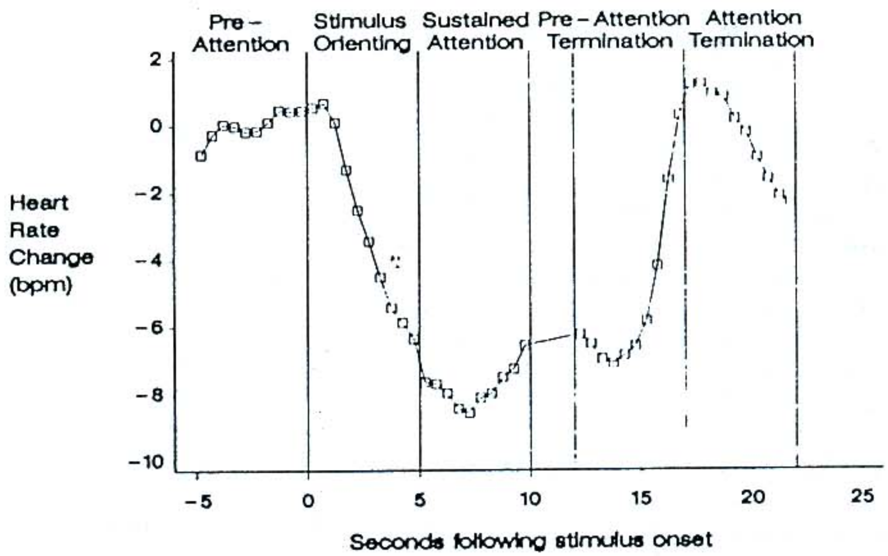

FIG. 2.1. The HR-defined information-processing phases (Copyright © 1990, The Society for Psychophysiological Research. Reprinted with permission of the publisher from Richards & Casey, 1991).

stimulus. The pre-attention termination period is not part of the model, but is an artifact of operational definitions of attention termination.

The first phase of attention is the *automatic interrupt* component (Graham, 1979). This phase represents a system that detects transient changes in environmental stimulation (e.g., the presence of a new stimulus). Without further stimulus processing, a brief bi-phasic HR response (deceleration–acceleration) occurs. For long duration rise time transients, an overt HR response often does not occur or is brief. The "startle reflex" is a manifestation of the automatic interrupt system, and occurs in response to short rise time or high intensity stimulation. This system is automatic (i.e., requires little or no processing resources, does not habituate, and is independent of stimulus intensity or total stimulus duration). Short-latency nervous system pathways control this response. This response activates the next phases of attention controlled by longer latency pathways. Graham, and Hoffman and Ison, give a more detailed description of the automatic interrupt system in other chapters.

The second phase of attention defined by HR change is *stimulus orienting*. This phase is identical to the orienting reflex (OR) studied by Sokolov (1963; cf. Graham & Clifton, 1966). During this phase the infant evaluates stimulus novelty, processes preliminary stimulus information, and decides whether to allocate further mental resources (Kahneman, 1973). The phase of stimulus orienting reflects activity early in the information-processing system. Stimulus orienting may represent more than just a "call" for later processing, but may also involve stimulus processing and resource demands (Siddle & Spinks, this volume). The automatic interrupt and stimulus orienting systems are similar in that both are reflexive and once elicited generally follow the same time course regardless of subsequent input. HR change during stimulus orienting consists of a large deceleration, lasting about 5 seconds. The level of the HR OR depends on the relative novelty of the stimulus. Siddle and Spinks, Pearce and Hall, and Ohman present other characteristics of stimulus orienting in this book.

The third of the HR-defined information-processing phases is *sustained attention* (Porges, 1976, 1980; Richards, 1987, 1988a). The OR is maintained or amplified during this phase in order to process-detailed stimulus information. This phase is under subject control, and thus it is more complexly determined than the other phases. Individual differences may be observed at this processing level because it requires active, subject-controlled cognitive processing. Developmental change occurs in this phase of attention. The developmental change is an increase in the efficiency of stimulus processing with an increase in age. HR is lower than prestimulus levels during this phase, has decreased levels of variability, and is accompanied by decreased respiration amplitude, inhibition of body movements, and other bodily changes (Jennings, 1986). The beginning of sustained attention occurs 4–5 sec fol-

lowing visual fixation. The duration of sustained attention is variable, lasti from as short as 2–3 sec, to 15 or 20 sec. Its duration depends on the state the infant, the relative novelty of the stimulus, stimulus complexity, a characteristics of the subject.

A final phase of visual information processing marked by HR is *attenti termination* (Richards, 1988a, 1988b). During attention termination the infa continues to fixate on the stimulus, but does not process information in t stimulus. The infant's sensitivity to new stimuli may be attenuated duri this phase (Casey & Richards, 1988, 1991; Richards & Casey, 1991). HR this phase returns to prestimulus levels and variability. Subject-initiat termination of stimulus presentation (looking away) or experimente initiated termination (turning the stimulus off) results in a brief and small H deceleration, the HR offset response (Richards, 1988b). The beginning attention termination is difficult to define. In previous research, it has be defined as when HR returns to prestimulus level (e.g., Richards, 198 However, this may be in the middle of the phase rather than its onset. T phase itself may begin before HR has fully returned to prestimulus lev (e.g., "pre-attention termination" in Fig. 2.1). A "predictive" HR mo would be necessary to be able to operationally define this phase with HR order to do a priori experimental manipulations. An alternative strate would be to probe at several intervals when attention termination might expected to begin, and then examine in a post hoc manner the HR level wh the probe occurred. The duration of attention termination is approximatel sec (Casey & Richards, 1991; Richards & Casey, 1991).

BEHAVIORAL RESEARCH SHOWING ATTENTION PHASES IN INFANTS

One of the first persons to distinguish between different phases of attent based on behavioral observations was Cohen (1972, 1973). He propose distinction between attention-getting properties of a stimulus, and attentio holding. This was a useful distinction, particularly for the infant-cont method (Cohen 1972; Horowitz, Paden, Bhana, & Self, 1972). The infa control method consists of the presentation of a stimulus for as long as infant looks at it. The time between the stimulus onset and fixation onset attention getting, and the duration of fixation was attention-holding. attention-getting referred to the ability of the stimulus to attract fixatio the direction of the stimulus. Attention-holding was the ability of the sti ulus to sustain fixation. Many studies of infant fixation and visual attent (e.g., Cohen, 1972, 1973; Cohen, DeLoache, & Rissman, 1975; DeLoac Rissman, & Cohen, 1978; Finlay & Ivinkis, 1982, 1984) have investiga infant visual attention with this procedure.

Cohen's distinction between attention-getting and attention-holding is an improvement over methods that simply use duration of fixation as the measure of attention (e.g., infant control: Cohen, 1972, and Horowitz et al., 1972; visual preference: Fantz, 1963). These experimental methods may not fully distinguish between different types of cognitive activity, or differing cognitive information-processing phases, occurring during visual attention. In Cohen's (1972, 1973) distinction, it is the duration of fixation on the visual stimulus that is the measure of attention-holding. Length of fixation by itself cannot be used to distinguish different types of cognitive activity. For example, the infant may be looking and actively attending to the stimulus, engaging in intensive examination of the properties of the stimulus, and actively processing the information contained in it. On the other hand, the infant may be fixating in the direction of the stimulus without any active processing of the stimulus. Also, active processing of the information in the stimulus may have different purposes. The infant may be attending in a manner that leads to familiarization, or may be orienting to a new stimulus without acquiring memory for it.

Another researcher who distinguished among phases of attention is Ruff (1986a). She labeled her phases "components" of attention. Ruff distinguished these components with the latency to touch small, graspable objects, and object examination time. Ruff (1986a) compared the latency to touch the object favorably with "reactive attention" (Porges, 1976, 1980), and "attention-getting" (Cohen, 1972, 1973). Focused attention is measured by object examination time, defined as the amount of time the infant engages in grasping, mouthing, and visually exploring the object ("sustained attention": Porges, 1976, 1980; "attention-holding": Cohen, 1972, 1973). Ruff and her associates have studied the development of focused attention in infants older than 6 months (e.g., Ruff, 1986a; Ruff & Lawson, 1990). They have also examined focused attention in preterm infants (Ruff, 1986b; Ruff, Lawson, Parrinello, & Weissberg, 1990; Ruff, McCarton, Kurtzberg, & Vaughan, 1984), and the stability of focused attention from 1 to 3.5 years (Ruff et al., 1990). Recently, Saltarelli, Ruff, and Capozzoli (1990) extended the use of object examination time to include distraction by a peripheral stimulus in the measurement of focused attention (e.g., dual-task procedure).

Ruff (1986a) used the duration of "object examination time," that includes looking, grasping, mouthing, and visually exploring the object. This definition of sustained attention correctly measures behaviors that represent active information processing. Thus, it is an improvement over methods that simply use visual fixation. It would be useful to correlate object examination time with HR changes to get a multioperational definition of sustained attention. This method is of limited usefulness to the study of just visual attention because object examination as defined by Ruff includes several nonvisual behaviors. Those nonvisual behaviors may interfere with visual attention measurement or occurrence. There also may be periods of sustained visual attention without examination by nonvisual behaviors.

Recently, Richards introduced a method for studying sustained attention and attention termination in infant visual information processing (Richards, 1985, 1987). This method is the *interrupted stimulus* method. The interrupted stimulus method is similar to the dual-task method for measuring attention resource allocation. This method of using an interrupting stimulus to measure cognitive-processing demands is analogous to a probe stimulus method. Researchers have used the dual-task method in disparate research areas, such as automaticity (Logan, 1979), perceptual learning (LaBerge, 1973), classical conditioning of autonomic responses (Dawson, Schell, Beers, & Kelly, 1982), and ERP measures of information-processing allocation (Wickens, Kramer, Vanasse, & Donchin, 1983). The dual-task procedure has been used with older children (Hagen, 1967; Hallahan & Reeve, 1980; Manis, Keating, & Morrison, 1980; Schiff & Knopf, 1985). Performance on the primary and secondary task shows an increase in cognitive resources over the early school years (e.g., Guttentag, 1989; cf. Brainerd & Reyna, 1989, and commentaries). Resource allocation is operationally defined in these methods as the reaction time (or error rate) to perform on a secondary task, or to respond to a probe stimulus (also see Siddle & Spinks, this volume)

Figure 2.2 illustrates the sequence of events for this method. A central visual stimulus occurs for as long as the infant fixates on it. After some delay, a stimulus is presented in the periphery in an attempt to distract the infant's fixation from the central visual stimulus. The central stimulus ends when the infant looks away from the central stimulus toward the peripheral stimulus. The delay at which the second stimulus begins depends on the phase of attention of interest. The dependent variable is the amount of time that the infant continues to attend to the central visual stimulus after the peripheral stimulus began. Sustained attention involves active stimulus processing, and thus requires processing resources. If the infant engages in central stimulus processing, he or she should remain fixated on it. The infant will not respond to the second stimulus until central processing ends. Thus, the sustained attention phase is the time when the infant cannot be distracted by the peripheral stimulus. The attention termination phase of infant information processing is the period of time when the infant is looking at the central stimulus, but could be distracted by the second stimulus.

HEART RATE RESEARCH SHOWING ATTENTION PHASES IN INFANTS

Sustained Attention

The interrupted stimulus method has been used with HR to study the sustained attention phase of infant cognitive processing (Casey & Richards

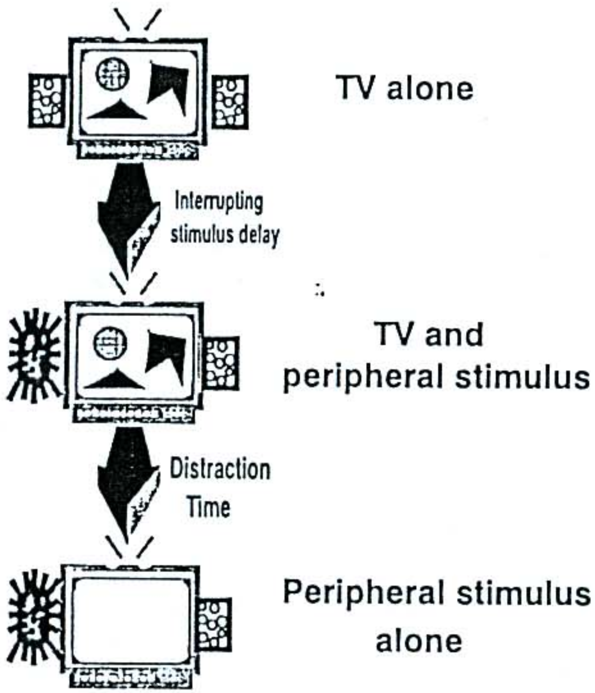

FIG. 2.2. The interrupted stimulus method for assessing infant visual attention.

1988; Richards, 1985, 1987, 1988b, 1989a, 1989b, 1990b). Active central stimulus processing presumably coincides with lack of distractibility by the peripheral stimulus. This active central processing requires the allocation of cognitive resources, and should result in concomitant HR changes (Jennings, 1986; Kahneman, 1973). Sustained lowered HR, hypothesized to be a marker of sustained attention (Fig. 2.1), should occur with longer delays to respond to the peripheral stimulus in the interrupted stimulus paradigm. The return of HR to its prestimulus level, hypothesized to mark the beginning of attention termination, should be associated with shorter delays to respond to the peripheral stimulus. Behavioral (distractibility) and physiological (sustained lowered HR) indices of sustained attention should be complementary tools for assessing the presence of sustained attention.

The research using the interrupted stimulus method has shown that sustained attention and attention termination in the young infant correlate with characteristic HR responses. For example, in Richards (1987), 3- to 6-month-old infants were presented with a complex visual pattern on a TV monitor. The interrupting stimulus was a set of blinking lights presented at the side of the monitor. The interrupting stimulus occurred at different delays following the central stimulus presentation. The delays were 3 or 7 sec, or defined by

fixation-induced HR changes (deceleration or return to prestimulus). Figure 2.3 illustrates the HR change associated with those four conditions. On HRDEC (HR deceleration) trials the interrupting stimulus occurred when HR decelerated significantly below the prestimulus HR level. On HRACC (HR acceleration) trials the interrupted stimulus occurred when HR returned to prestimulus levels following a significant HR deceleration. The similarity of the HR responses in Fig. 2.3, and the model of Fig. 2.1, indicates that these operational definitions result in HR changes matching the HR-defined phases.

The HR changes correlated with peripheral stimulus distraction times. Attention status can be defined by HR independent of time of occurrence. It took longer to distract infants on the HRDEC trials (6.58 sec) than on the HRACC trials (3.29 sec). Alternatively, the interrupting stimulus delay can be defined by time, and attention status can be defined by the HR response on those trials. On both 3- and 7-sec trials, if the HR response was at or below that defined on the HRDEC trials (− 9.52 bpm), it took 6.48 sec to distract the infant to look toward the interrupting stimulus. On those 3- and 7-sec trials if the HR response was at or above that defined on the HRACC trials (− 1.64 bpm), it took 4.64 sec to distract the infant. If HR on those trials was at a level intermediate between the HRDEC and HRACC trials, the distraction time was also at an intermediate level (5.27 sec). Thus, the passage of time by itself cannot be used to distinguish sustained attention and attention termination. Rather, the HR response at specific times provides information about the status of the information-processing system. The behavioral observations confirm the hypothesis that HR deceleration and sustained HR lowering occur during sustained attention, and the return of HR to prestimulus levels occurs during attention disengagement. These results have been

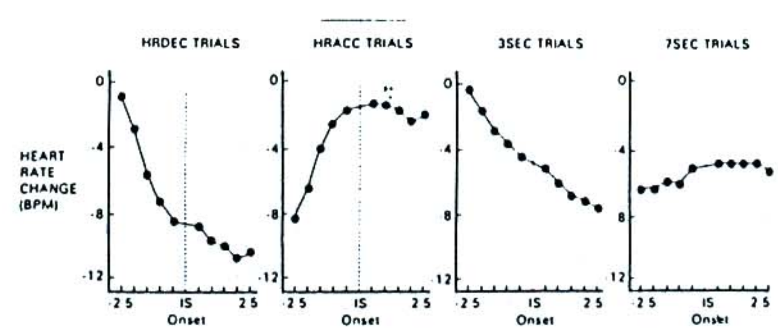

FIG. 2.3. HR changes occurring during experimental conditions designed to assess sustained attention and attention termination (Copyright © 1987, The Society for Research in Child Development, Inc. Reprinted with permission of the publisher from Richards, 1987).

replicated in several studies (Casey & Richards, 1988; Richards, 1985, 1987, 1988b, 1989a, 1989b, 1990b).

The 3- and 7-sec interrupted stimulus delay has been used in several studies (Richards, 1987, 1989a, 1989b, 1990b) as a comparison condition for the fixation-induced, HR-defined delays (HRDEC and HRACC). The 3-sec condition was originally chosen as a time near the onset of sustained attention. However, the average of the onset of the HR deceleration in those studies was 3.62 sec. A time-defined delay of 4 sec is currently used as a control for the HRDEC condition. The 7 sec condition was included in those studies as a time when the infant should be in the middle of sustained attention. The behavioral and HR evidence suggest that 7 sec was appropriate for that control. The average time for the return of HR to its prestimulus level has been 10.28 sec. Appropriate controls for the attention termination condition are now included as well (e.g., interrupted stimulus delay at 10 sec).

The hypothesis that sustained attention represents active stimulus processing can be tested with methods other than the interrupted stimulus method. Recently, we examined the distribution of fixations to "novel" and "familiar" stimuli in the paired-comparison, recognition memory paradigm (Fagan, 1982) as a function of the HR-defined phases (Richards & Casey, 1990). The paired-comparison method, like the visual preference method (Fantz, 1963), involves the presentation of two stimuli simultaneously. The infant receives a pre-comparison exposure to one of the stimuli, the "familiar" stimulus. In the subsequent paired-comparison phase, the infant prefers the nonexposed stimulus, the "novel" stimulus. Novelty preference represents recognition of the familiar stimulus. It also indicates the infant's interest in processing the information in the new stimulus. If novelty preference represents active processing of the new stimulus, then it should occur most strongly during sustained attention.

The relation between exhibition of novelty preference and HR-defined attention phases was examined by assessing novelty preference during the phases (Richards & Casey, 1990). Infants ranging in ages from 3 to 6 months were presented with a standard familiarization/paired-comparison trial (recognition memory), and a trial without the familiarization phase (visual preference). The ongoing HR was measured, and stimulus orienting, sustained attention, and attention termination defined according to the expected HR changes (Fig. 2.1; cf. Richards, 1987). As hypothesized, novelty preference during the test for recognition memory was strongest during sustained attention. Sustained attention lasted for 11.8 sec on the recognition memory trials. The infants looked at the novel stimulus for 7.3 sec during sustained attention, but at the familiar stimulus for only 4.5 sec. On the visual preference trials (no familiarization phase), sustained attention lasted for 9.8 sec. The infants looked for equal durations at the two stimuli, both of which were novel (5.1 and 4.7 sec, respectively) during sustained attention. Infants looked at the novel and familiar stimuli with equal durations during attention termination on both the visual preference and recognition memory trials (visual preference: 3.57 and 3.38 sec for two stimuli; recognition memory: 2.73 and 3.08 for familiar and novel stimuli, respectively). The infants also looked away from both stimuli during attention termination more often and with longer durations than during the other phases. This was expected because stimulus orienting and sustained attention involve active intake of stimulus information, whereas attention termination is "information-resistant."

Individual Differences in Sustained Attention

Sustained attention is "voluntary" (i.e., under subject control). Thus, it is more complexly determined than the other phases. Individual differences may be observed during this phase because it requires subject-controlled cognitive processing. The analysis of attention into separate components, using behavioral and HR measures, has shown that individual differences in sustained attention exist. These individual differences correlate with baseline levels of HR variability.

Several years ago, researchers demonstrated that newborns with high levels of HR variability have larger mean HR responses to visual and auditory stimuli than newborns with low HR variability (Porges, Arnold, & Forbes, 1973; Porges, Stamps, & Walter, 1974; Vranekovic, Hock, Isaac, & Cordero, 1974; Williams, Schacter, & Tobin, 1967). Recently, it has been shown that the specific type of HR variability that correlates with infant attentional responses is respiratory sinus arrhythmia (RSA) in HR. A description of RSA is that HR accelerates and decelerates at the same frequency of respiration inspiration and expiration. Infants from 14 to 26 weeks of age with high baseline RSA have larger and more sustained HR responses in sustained attention than do low RSA infants (Casey & Richards, 1988; Richards, 1985, 1987, 1989a). For example, defining low and high RSA groups with a median split, low RSA infants have an average HR decrease from baseline during sustained attention of about −7 bpm. High RSA infants have a response of −11.6 bpm (Casey & Richards, 1988; Richards 1987, 1989a). The HR responses during stimulus orienting and attention termination do not correlate with RSA level. Table 2.1 has correlations from a study of 14- to 26-week-olds (Richards, 1985, and unpublished data from Richards, 1987), and 8-week-olds (Richards, 1989b). The HR changes in stimulus orienting and attention termination do not correlate with RSA. The HR changes in sustained attention correlate with RSA, but not with total HR variance.

Behavioral measures of sustained attention also correlate with baseline levels of RSA. Infants with high baseline levels of RSA have better organized sustained attention during distraction tasks, recognition memory, and habit-

Table 2.1 Correlation of Baseline HR Variability and HR Changes During the HR-defined Attention Phases (from Richards, 1985, 1987, 1989b)

Age	Attention Phase	
	Stimulus Orienting	
	Variance	RSA
8 weeks	−.14	.20
14, 20, 26 weeks	−.08	−.03
	Sustained Attention	
	Variance	RSA
8 weeks	−.36*	−.46**
14, 20, 26 weeks	−.19	−.42**
	Attention Termination	
	Variance	RSA
8 weeks	−.09	.05
14, 20, 26 weeks	−.01	.12

*$p < .05$; **$p < .001$

uation tasks, than do infants with low baseline levels of RSA. Infants with high baseline RSA are not as easily distracted by a peripheral stimulus in the interrupted stimulus method as are infants with low baseline levels. This is true only for the conditions in which sustained attention occurs (cf. HRDEC vs. HRACC in Richards, 1987). For example, if the peripheral stimulus in the interrupted stimulus method was delayed until a significant HR deceleration occurred (HRDEC trials, Richards, 1987), high RSA infants continued to look at the central stimulus for an additional 7.52 sec. Low RSA infants were more easily distracted (5.60 sec). Distraction times for the high and low RSA infants were equivalent during attention termination (3.49 and 3.09 sec for low and high RSA infants, respectively, HRACC trials, Richards, 1987).

Individual differences in baseline RSA correlate with recognition memory and the distribution of novelty preference in the attention phases. Linnemeyer and Porges (1986) reported that low RSA infants had lower novelty preference scores in the paired-comparison/recognition memory paradigm than did high RSA infants. In the study mentioned previously (Richards & Casey, 1990), novelty preference occurred primarily during sustained attention (previous section). Further, the infants with high baseline RSA had higher novelty preference scores during stimulus orienting and sustained attention than did low RSA infants. During stimulus orienting, the high RSA infants looked at the novel stimulus for 1 sec longer than the familiar stimulus, whereas low RSA infants looked at the stimuli with equal durations. During sustained attention, the high RSA infants looked at the novel

stimulus for 2.32 sec longer than the familiar stimulus, whereas the difference for low RSA infants was only 1.02 sec. The novelty preference of the high RSA infants fluctuated very little within sustained attention. Novelty preference of low RSA infants was inconsistent during sustained attention and attention termination. The high RSA infants, compared to the low RSA infants, allocated processing resources to the psychologically relevant, novel stimuli, and distributed looking time appropriately across attention phases. Thus, it is not just general responsivity that correlates with RSA. Rather, it is the organization of responses during sustained attention that correlates with individual differences in RSA level.

Why should individual differences in RSA level correlate with individual differences in sustained attention? The relation between RSA and sustained attention involves brainstem and central HR mechanisms. Brainstem respiratory centers control the rhythmic changes in HR (Daly, 1986; Grossman, 1983; Lopes & Palmer, 1976; Spyer, 1979). Efferent innervation from the vagus nerve to the heart mediates the central nervous system control of these HR rhythms (Anrep, Pascual, & Rossler, 1935; Katona & Jih, 1975; Porges, McCabe, & Yongue, 1982). Thus, RSA is a measure of vagal parasympathetic activity on the heart. Researchers assume that vagal parasympathetic activity mediates the phasic changes in HR during attention (Graham, 1973; Graham & Clifton, 1966; Obrist, Webb, Sutterer, & Howard, 1970; Richards & Casey, 1991; cf. Bernston, Porges, this volume). Cardiac variability attributable to RSA may measure individual differences in the capacity of the heart to respond during attention.

However, a theory of the relation between RSA and sustained attention must be both more general and more specific than just involving HR responsivity. It must be more specific, because it is only the sustaining of the HR response that correlates with RSA. The level of responsivity during stimulus orienting does not correlate with baseline RSA. It must be more general because HR and behavioral responses correlate with RSA levels.

Porges (1976, 1980, this volume) and Richards (1988a) offer theories describing the relation between sustained attention and RSA. Both posit that RSA level serves as an index of individual differences in sustained attention. Porges (1976, 1980) postulates that RSA level, as a measure of vagal tone, indexes the level of the "cholinergic nervous system." This cholinergic system mediates the HR changes in attention, particularly sustained attention. They indirectly index the capacity of the brain to affect attention-related behaviors during attention events. Richards (1988a) proposed that RSA level may be an index of the functional integrity of the brainstem centers controlling respiration. It indirectly measures brainstem functional capacity to control attention by measuring its capacity to control state, arousal, and attention. This would be consistent with the pathology patterns of attentional control found in preterm infants (e.g., Richards, 1990b; Ruff, 1986b), particularly those with respiratory problems and possible minimal brain damage in the brainstem.

Another possible reason that RSA levels correlate with attention is the relation of cardiac control to the cerebral cortex. The decrease in HR found during attention is in part caused by "cardioinhibitory" centers in the frontal cortex (Powell & Buchanan, 1989), the agranular prefrontal cortex (AgPfC; Korner, 1979; Powell & Buchanan, 1989). The AgPfC has descending monosynaptic efferents to areas of the brainstem that control vagal efferent activity to the heart (Korner, 1979; Krettek & Price, 1977; Krushel & van der Kooy, 1988; Neafsy, Hurley-Guis, & Arvanitis, 1986; van der Kooy, Koda, McGinty, Gerfen, & Bloom, 1984). Descending projections from the AgPfC go to the septum, central nucleus of the amygdala, and the hypothalamus. The hypothalamus (anterior and dorsal regions) has reciprocal connections to the brainstem areas involved in vagal efferent activity on the heart. These systems control a widespread functional system involved in cardiovascular function. Stimulation of these structures at some sites has large depressor effects (arterial pressure decreases and bradycardia) typical of those found in attention (Hugelin, 1986; Korner, 1979). Lesions in many of these areas cause a lack of cardiac effects often found in behavioral studies, such as conditioned bradycardia (Powell & Buchanan, 1989). Thus, the HR changes during visual fixation index alerting occurring during stimulus orienting, and index information-processing functions found during sustained attention.

The relation between sustained attention, RSA level, brainstem RSA control, and cerebral cardiac control, suggests that RSA may index many complex behavioral functions (cf. Porges, this volume). Many of the areas involved in cardiac control belong to the limbic system and, as such, may be involved in emotional and motivational aspects of behavior. HR variability correlates with social and personality characteristics of infants. Kagan and his colleagues have established a link between children with a behaviorally inhibited personality style and low levels of HR variability (Kagan, Reznick, & Gibbons, 1989; Kagan, Reznick, & Snidman, 1989). RSA level correlates with developmental level (Fox & Porges, 1985; Richards & Cameron, 1989), emotional reactivity (Fox, 1989; Stifter & Fox, in press), and parental ratings of infant temperament (Healy, 1989; Richards & Cameron, 1989). Patterns of attention and temperament are predictable by individual differences in resting HR. The relation between individual differences in attention, and individual differences in temperament, has been the focus of recent theories of infant temperament (Fox, 1989; Rothbart & Derryberry, 1982; Rothbart, Halstead, & Posner, 1990). Individual differences in attention may form the basis for individual difference in socioemotional behavior. Alternatively, control of attention and socioemotional behavior may be associated with cortical systems that have a general effect on several complex behavior systems.

Development of Sustained Attention

Developmental changes in infant sustained attention may occur for several reasons. First, there are several brain systems controlling visual behavior that develop rapidly from birth to 6 months (Bronson, 1974; Johnson, 1990; Maurer & Lewis, 1979; Richards, 1990a). This is particularly true for those visual systems that involve attention-directed visual processing. Thus, one might expect increases in the levels of the sustained attention rather than the other phases because it is the most complex of the attention phases. Second, there are changes in HR variability from birth to 6 months of age. Overall HR variability and RSA levels increase (Harper, Hoppenbrouwers, Sterman, McGinty, & Hodgman, 1976; Harper et al., 1978; Katona, Frasz, & Egbert, 1980; Richards, 1985, 1987, 1989b; Watanabe, Iwase, & Hara, 1973). These changes may be due to the increasing influence of the parasympathetic nervous system on HR variability (Egbert & Katona, 1980). Because attentional responses are coupled with the processes controlling RSA level, developmental changes in RSA should affect the development of the attentional system.

Studies using the interrupted stimulus method (Richards, 1985, 1987, 1988b, 1989a, 1989b) have found developmental change in sustained attention. The ages of the subjects in these studies were 8, 14, 20, or 26 weeks of age (2 to 6 months of age). For example, in one study (Richards, 1985), HR changes to complex visual stimuli were recorded in 14-, 20-, and 26-week-old infants. There were no age differences in the HR responses occurring in the first few seconds of visual fixation, the stimulus orienting phase (Fig. 2.4; cf. Graham et al., 1970, Figure 1). In the sustained attention phase, the magnitude of the HR responses increased over this age range. Cognitive resource allocation correlates positively with the magnitude of physiological responses (Jennings, 1986; Kahneman, 1973). Thus, this age difference in sustained HR responses implies that there is an increase in the allocation of information-processing resources. Another developmental change was a decline in the time necessary to distract the infant from looking at the central stimulus. However, the decline in distraction times over this age range did not differ for the experimental procedures differentiating sustained attention and attention termination (cf. Ruff, 1986a; refer to prior section on behavioral methods).

As expected, there was an increase in the level of the HR response during sustained attention that paralleled increases in baseline RSA level. Table 2.2 presents data from four studies showing changes in baseline HR functions and attention-related HR for infants from 8 to 26 weeks of age. Baseline HR mean decreases over this age range, and baseline RSA amplitude increases (Harper et al., 1976; Harper et al., 1978; Katona et al., 1980; Watanabe et al., 1973). The HR change on the HR deceleration trials, when sustained atten-

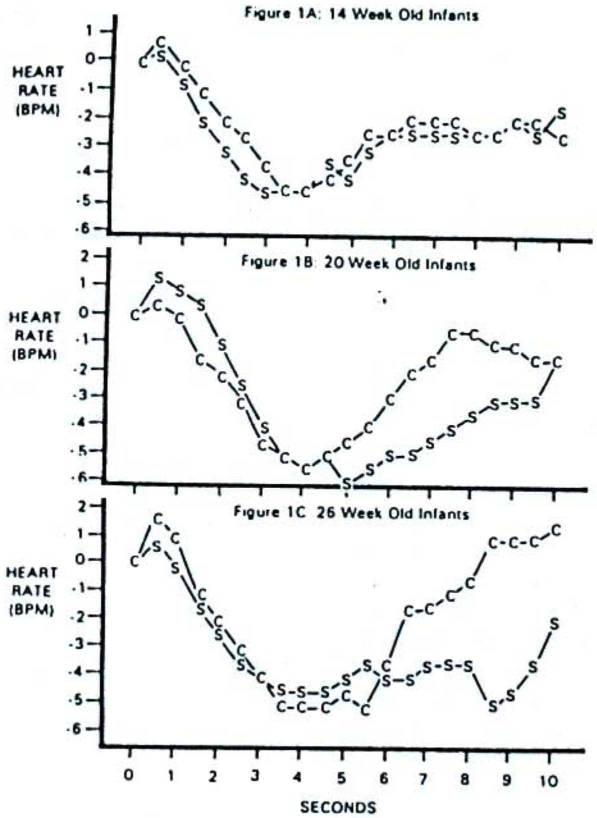

FIG. 2.4. Heart rate changes during fixation for 14-, 20-, and 26-week-old infants for the interrupted stimulus procedure ("S") and the infant control procedure ("C") (Copyright © 1985, The Society for Psychophysiological Research. Reprinted with permission of the publisher from Richards, 1985).

tion was occurring, was similar in the 8-week-olds to the 14-week-olds, but increases thereafter. The smaller amplitude of RSA at 8 weeks results in smaller HR changes during the HR deceleration trials. The HR response on the HR acceleration trials does not change with age.

The parallel developmental changes in RSA and HR responses during sustained attention are more than mere coincidence. The relation between developmental changes in RSA and changes in sustained attention HR from 3 to 6 months of age was investigated using the interrupted stimulus procedure (Richards, 1989a). Infants were tested longitudinally at 14, 20, and 26 weeks of age. RSA was measured in a baseline period, and HR changes were measured during sustained attention. Intraindividual development in baseline RSA was paralleled by changes in HR during sustained attention. The four possible patterns of RSA change over age (e.g., increase, decrease, increase–decrease, decrease–increase) closely matched the HR changes during sustained attention. The relative level of RSA over the entire testing period paralleled the relative level of HR change during attention over the same testing period. Fluctuations in the RSA system that are local to a testing age also occur as fluctuations in the attention system. Sustained attention development may be based on the change in RSA over this time period, and the close association between RSA and sustained attention.

Table 2.2 Average Values for Infants at 8, 14, 20, and 26 Weeks of Age for Baseline HR and Attention-Linked HR Changes (from Casey & Richards, 1988; Richards, 1987, 1989a, 1989b. Copyright © 1989, Ablex. Reprinted with permission of the publisher from Richards, 1989b).

	Testing Age			
	8 Weeks	14 Weeks	20 Weeks	26 Weeks
Baseline Recording				
Heart rate	152.6	151.5	146.3	144.2
Heart rate variance	7.35	9.78	9.44	8.16
RSA	0.68	1.40	1.78	2.17
Experimental Trials				
Heart rate change on deceleration trials	−6.9	−6.9	−8.5	−11.0
Heart rate change on acceleration trials	−1.7	−2.8	0.3	0.3
Distraction time over all procedures	7.37	6.84	4.39	3.25

A parallel may be made between human attention changes, RSA changes, and changes in the young rat (cf. Campbell, Richardson, & Hayne, this volume). Rat pups have typical HR-orienting responses to auditory, visual somesthetic, oral, and olfactory stimuli (e.g., Haroutunian & Campbell, 1981; Sananes, Gaddy, & Campbell, 1988; Siegel, Sananes, Gaddy, & Campbell, 1987; Wigal, Dailey, & Amsel, 1985). For example, the rat has an acceleratory HR response to auditory and visual stimuli through postnatal day 16 and this changes to a deceleratory response at 16 days (Haroutunian & Campbell, 1981). This age range, and the change from cardioacceleratory to deceleratory responses, corresponds to human newborn responses (acceleratory) and responses of 2- to 3-month-old infants (deceleratory) (Berg & Berg, 1987; Graham & Jackson, 1970). From postnatal day 15 to 20, the rat has an increasing level of the bradycardia in response to stimuli of various sensory modalities. This corresponds to developmental changes in the first 1–3 months in the HR response of human infants to auditory stimuli. As with the human infant, there are parallel changes in vagal activity over this period of development. The onset of tonic vagal activity occurs in the rat pup about 15–16 days of age (Adolph, 1967, 1971; Seidler & Slotkin, 1979; Wekstein, 1965). There are increases in level of RSA across the age range of 1 to 16 days in the rat (Larson & Porges, 1982; cf. Porges, this volume). The onset of tonic vagal activity at 16 days coincides with the onset of the HR deceleration response found in stimulus orienting (Haroutunian & Campbell, 1982). The changes in RSA level across this age in the rat parallel the increasing responses of HR and behavior during attention. Thus, the developmental changes in the HR attention responses in the rat, and potential age-correlate of the response with RSA, parallel changes in human infants.

Sustained Attention in Preterm Infants

Preterm infants are vulnerable to deficiencies in sustained attention. The medical complications causing the premature birth often cause respiration deficiencies, including anoxia and asphyxia. Another complication associated with preterm births is Respiratory Distress Syndrome (RDS). RDS occurs in preterm infants because the control mechanisms for breathing and the lungs are underdeveloped in preterm infants with early gestational ages (Burri, 1985). Infants born early in the third trimester are at risk due the lack of quantity of lung surfactant, and the lung surfactant's chemical immaturity. The result of the RDS leads to an inefficiency of oxygen transport across the blood-air barrier of the lungs, which causes chronic hypoxia (Burri, 1985). The lack of oxygenation of brain tissue due to RDS or to perinatal respiratory complications, may cause slight damage to the brain. This damage often can be indexed by damage to cardiac and respiratory control (e.g., fixed HR, no RSA, apneas). This "minimal" brain damage is reflected in the poor attentional control of the preterm infant, reflected in behavioral and HR responses during attention.

The cardiac attentional responses of preterm infants differ from normal full-term infants. In comparison with full-term infants, the HR response of the preterm infant is weaker (Bench & Parker, 1971; Berkson, Wasserman, & Behrman, 1974), and the HR response often fails to habituate with repeated stimulus presentation (Field, Dempsey, Hatch, Ting, & Clifton, 1979; Schulman, 1970a). Behavioral and cardiac responses are less well integrated (Field et al., 1979; Rose, Schmidt, & Bridger, 1976). Preterm infants with likely central nervous system (CNS) damage (Schulman, 1970b), or preterm infants with RDS (Fox & Lewis, 1983), exhibit less mature HR responding than do healthy preterm or full-term infants.

High-risk infants have different patterns of sustained attention than low-risk infants. Ruff (1986b; also, Ruff et al., 1984) used object examination time as a measure of sustained attention because it involves the active intake of stimulus information. At the age at which object examination first appears (around 6 months), preterm infants spent considerably less time in object examination than did full-term infants. This difference disappeared for healthy preterm infants at 9 months of age, but continued for high-risk infants. High-risk preterm infants at 6 and 9 months also do poorer than

full-term or healthy preterm infants on novelty preference (Rose, 1983; Rose, Feldman, McCarton, & Wolfson, 1988).

Preterm infants as a group have lower levels of RSA than full-term infants. This is especially true for "high-risk" preterm infants with RDS (Kero, 1974; Rother et al., 1987). Because RSA indexes individual differences in sustained attention in normal infants, the depressed levels of RSA known to exist in preterm infants may parallel their attentional deficiencies (Richards, 1988a). Thus, sustained attention may be poorly organized in preterm infants (similar to low RSA full-term infants) compared with high RSA full-term infants. These attention pathologies may be diagnostic signs for poor psychological outcome, as a relation exists between early measures of visual attention and later psychological outcome (Rose, Feldman, & Wallace, 1988; Rose & Wallace, 1985). Older children with RDS and attention-deficit disorder children have similar patterns of attention. For example, RDS and attention-deficit disorder children have poorer sensitivity during vigilance tasks, and difficulty in sustaining their attention over time (O'Dougherty, Nuechterlein, & Drew, 1984).

Recently, a longitudinal study examined the development of sustained attention in healthy and "at-risk" preterm infants (Richards, 1990b). High-risk preterm infants had respiratory problems (e.g., RDS, asphyxia, needed ventilation), whereas low-risk infants were without severe prenatal or perinatal medical complications. The infants were tested in a longitudinal design at conceptional ages corresponding to full-term postnatal ages of 14, 20, and 26 weeks. The experimental method consisted of the interrupted stimulus method. The peripheral stimulus occurred during sustained attention (HRDEC trials) and attention termination (HRACC trials), or at time-based delays (3 or 7 sec) (i.e., Fig. 2.3).

Figure 2.5 presents the RSA and HR changes across the three testing ages. Figure 2.5 also includes the RSA and HR changes for full-term infants from other studies (Richards, 1987, 1989a). The high-risk and low-risk preterm infants at 3 months had smaller HR response than full-term infants during stimulus orienting and sustained attention. Similarly, RSA level was low for both preterm groups. Although they never fully caught up with full-term infants, the low-risk preterm infants had regular developmental increases in RSA. They also had concomitant increases in HR and behavioral measures of sustained attention. The high-risk group had little increase in RSA level over the period of testing, and had concomitant poor sustained attention at 6 months of age. Sustained attention had the same developmental course in low-risk preterm infants as in full-term infants, with a "developmental delay." The high-risk group had a continuing deficit in stimulus orienting and sustained attention over this same age, suggesting a more permanent attentional dysfunction. As in Richards (1989a), the development of sustained attention closely paralleled intraindividual development of RSA.

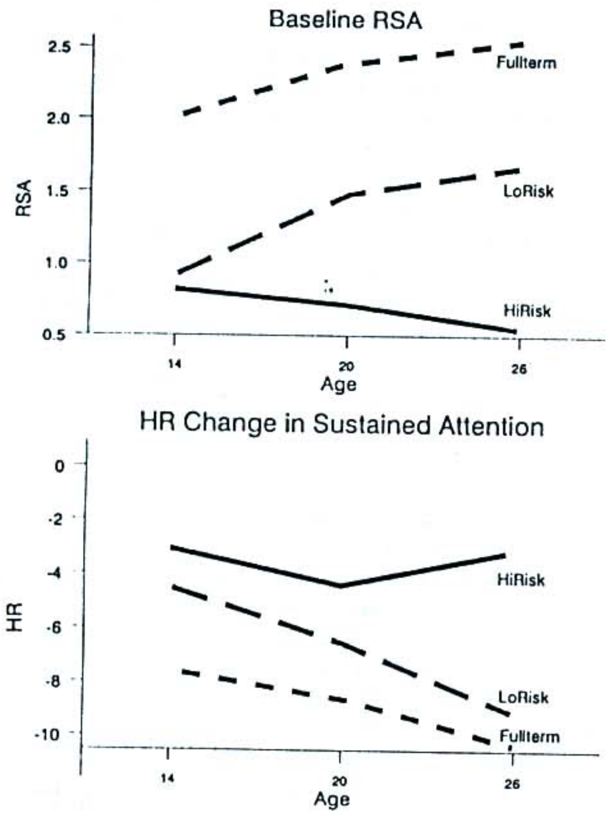

FIG. 2.5. RSA and HR changes from ages 14 to 26 weeks in full-term infants, and low-risk and high-risk preterm infants (Richards, 1990b).

Attention Termination

The sustained attention phase represents encoding of stimulus information, utilization of cognitive resources, and active attention. What happens when sustained attention ends? How does the infant switch from active involvement with a stimulus, to inattention? One possibility is that once sustained attention ends, the infant is in a state of "nonattention," and is ready to engage in processing of other stimuli (e.g., "pre-attention," Fig. 2.1). A second possibility is that a type of active disengagement must occur following sustained attention. Posner and Cohen (1982), for example, posit that disengagement from the stimulus is an active process controlled by the posterior parietal cortex. Disengagement is a sequential step in attention necessary before engagement can occur on other stimuli. The model proposed in this chapter has such a phase of attention, labeled *attention termination*. The infant is no longer engaging in active processing of the stimulus upon which he or she directs fixation during attention termination. Some period of time must elapse before the infant can appropriately respond to new stimuli. This phase of attention is "information-resistant" (Casey & Richards, 1988, 1991; Richards & Casey, 1991).

Behavioral and HR indices distinguish attention termination from the other attention phases. The infant in the interrupted stimulus paradigm responds quickly to localize the peripheral stimulus during attention termination (Casey & Richards, 1988; Richards, 1987, 1989a, 1989b). The response to the peripheral stimulus is as fast in attention termination as in the prestimulus period, and much faster than during sustained attention. In terms of the "dual-task" procedure, the infant does not allocate processing resources to the central visual stimuli during attention termination. Thus, performance on the second task (peripheral stimulus localization) improves. The HR during attention termination by definition is different from sustained attention. The sustained attention HR pattern is a sustained lowering of the HR level achieved in the stimulus-orienting phase. The HR during attention termination has returned to prestimulus level (Fig. 2.1, Fig. 2.3).

Even though the infant may localize the peripheral stimulus more quickly in attention termination, there is an attenuated HR response to that stimulus. The infant's HR response to a new stimulus is smaller in attention termination than in stimulus orienting (Casey & Richards, 1988, 1991; Richards, 1988b; Richards & Casey, 1991). In one study, for example, the length of the period of insensitivity to a new stimulus presentation was examined (Casey & Richards, 1991). A new central stimulus, replacing the currently fixated central stimulus, was presented to subjects at varying delays following attention termination. If the second stimulus occurred at 0 or 3 sec after HR returned to its prestimulus level (i.e., attention termination), the HR response was attenuated in comparison to the initial HR OR. A typical HR OR occurred if the new stimulus occurred at 6 or 9 sec following the return of HR to the prestimulus level (Fig. 2.6). The refractory period in the response to a new stimulus is paralleled by the HR response to stimulus offset. The HR attention response must be completed before the full HR offset response can be elicited (Casey & Richards, 1991; Richards, 1988b). The difference between the HR response to the first stimulus and to the second stimulus is consistent with the hypothesis of a refractory period following attention termination. During this refractory period an optimal HR deceleration cannot occur.

The decrease in distraction time during attention termination distinguishes it from the stimulus-orienting and sustained attention phases. The refractory period in the HR OR distinguishes attention termination from a "pre-attention" phase prior to stimulus onset. If the HR response is an index of

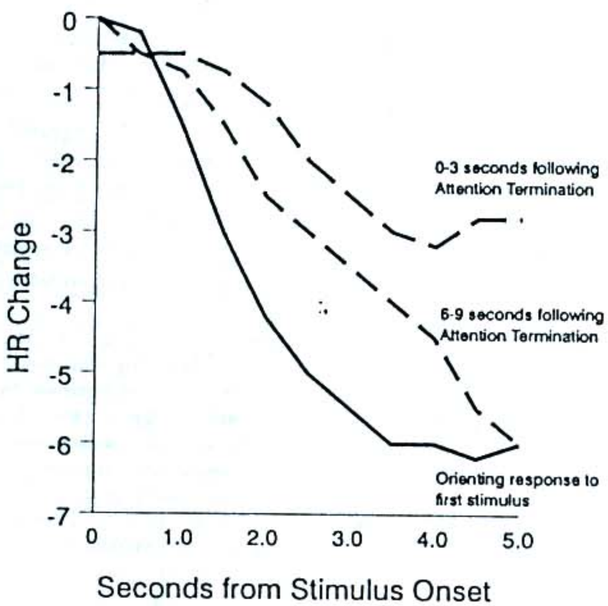

FIG. 2.6. The time course of the refractory period during attention termination (Casey & Richards, 1991).

ongoing cognitive processing activity, then the cognitive activity occurring during the onset response, the HR deceleration condition, and the HR acceleration condition are markedly different. Thus, offset to a stimulus and onset to another stimulus result in responses in attention termination that can be distinguished from those that occur following pre-attention or sustained attention. However, those pieces of evidence do not give direct support to the idea that the infant does not process information in the central stimulus during this phase. The lack of preference for the novel stimulus during attention termination in the recognition memory paradigm (Richards & Casey, 1990) implies that infants do not voluntarily direct fixation to appropriate, information-containing stimuli, during this phase. Direct evidence that less processing of central stimulus information occurs during attention termination would require that infants do not acquire stimulus information during this phase. For example, the to-be-remembered stimulus for a recognition memory paradigm ("familiar stimulus") might be presented exclusively during one of the attention phases. If processing is attenuated during attention termination, then novelty preference scores in the subsequent recognition memory phase of the paradigm should differ for stimuli presented solely during stimulus orienting, sustained attention, and attention termination.

Attention termination, unlike sustained attention, does not correlate with age or baseline RSA level. As with stimulus orienting, HR levels and HR responses are not different from 8 to 26 weeks of age, and do not correlate with baseline levels of RSA (e.g., Table 2.1; Casey & Richards, 1988, 1991; Richards, 1985, 1987, 1988a, 1989a; Richards & Casey, 1991). Unlike sustained attention, infants with high and low RSA are as easily distracted by the interrupting stimulus in attention termination (Richards, 1987). No developmental or individual differences in the duration of the refractory period for the HR during infant visual attention occur across the ages of 3 to 6 months (Casey & Richards, 1991). The characteristics of attention termination distinguish it from sustained attention (e.g., behavioral, HR changes, distraction time), and the functional relations with other variables distinguish it as well.

A NEURODEVELOPMENTAL MODEL OF SUSTAINED ATTENTION

The chapter thus far has presented a theoretical model and empirical data on visual sustained attention and its development in young infants. This information may be understood considering the brain systems controlling HR changes, sustained attention, and the developmental course of those brain systems. The extent and time course of the HR changes during visual fixation reflects CNS arousal. The lack of distractibility by a peripheral stimulus during sustained attention is controlled by cortical structures whose functions are enhanced during attention-linked arousal. Development of sustained attention occurs in both the arousal system and in the cortical structures controlling attention-directed fixation.

Broad-based structures in the mesencephalic reticular formation control the arousal component of visual attention. The mesencephalic reticular formation has a large influence on the limbic system, and a smaller direct influence on the parietal lobe (Heilman, Watson, Valenstein, & Goldberg, 1987; Mesulam, 1983). Limbic input into the parietal cortex area PG comes from the cingulate cortex. This part of the cingulate cortex receives input from the basolateral nucleus of the amygdala, the subicular portion of the hippocampus, and other areas of the limbic system. The cingulate cortex is a major afferent relay center that projects to PG, visual association cortical areas, and other cerebral cortex centers controlled in complex attention-directed areas. Figure 2.7 presents a model representing this arousal system.

Why would HR changes during visual attention be involved in this network? HR is an index of this mesencephalic reticular formation, and thus an index of nonspecific arousal. The areas of the limbic system (hypothalamus and amygdala) that project to the cingulate cortex, and indirectly to cortical attention centers, have descending projections to the vagus controlling the heart. They also project to the solitary nucleus controlling respiration. Elec-

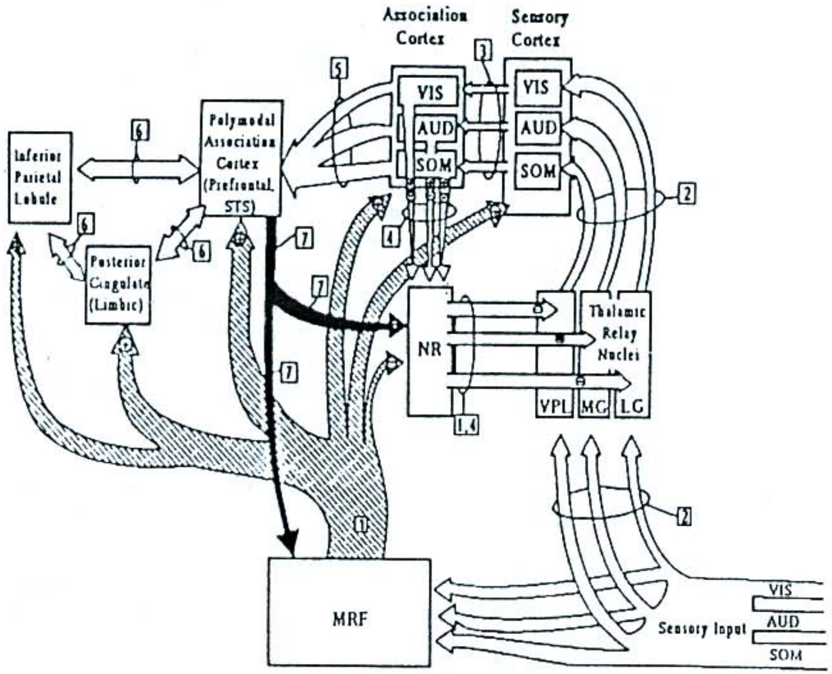

FIG. 2.7. The arousal system of the brain. 1: polysynaptic reticulocortical pathways; 2: sensory transmission; 3: associative cortex projections; 4: unimodal projections to reticular nucleus of the thalamus (NR); 5: sensory convergence to polymodal cortex; 6: supramodal cortex (inferior parietal lobule) and limbic connections; 7: cortical arousal through mesencephalic reticular formation (MRF) and NR. STS: superior temporal sulcus; VIS: visual; AUD: auditory; SOM: somatosensory; VPL: ventralis posterolateralis; MG: medial geniculate; LG: lateral geniculate (Copyright © 1981, American Medical Association. Reprinted with permission of the publisher from Watson, Walenstein, & Heilman, 1981, *Archives of Neurology, 38*, 501–507.

trical stimulation of these limbic areas has profound cardiac and respiratory effects similar to those found in emotional and attention responses. This general arousal system invigorates the cortical visual attention systems simultaneous with the control of HR changes via the brainstem. The HR-defined attention phases index the extent and time course of this arousal.

The infant's behavior in the interrupted stimulus paradigm involves two important visual pathways in the brain. The infant will not localize the peripheral stimulus while engaging in sustained attention to the central stimulus. Schiller (1985; cf. Johnson, 1990; Richards, 1990a) described, among others, two brain pathways involved in the saccadic localization of visual stimuli. A brain pathway controlling reflexive peripheral eye movements uses the broadband, magnocellular network (DeYoe & Van Essen,

1988; Livingstone & Hubel, 1988). This pathway goes from the retina to the superior colliculus and then onto the lateral geniculate nucleus. It involves a feedback system with the lateral geniculate nucleus, the primary visual cortex, and the suprasylvian cortex. This system controls reflexive eye movements to peripheral stimuli. Attention affects a brain pathway that controls targeted eye movements. This pathway is the narrowband, color-opponent "parvocellular" pathway (DeYoe & Van Essen, 1988; Livingstone & Hubel, 1988). It passes through the retina, lateral geniculate nucleus, visual areas 1 and 2, and the frontal eye fields. The frontal eye fields control the superior colliculi to control eye movements, or directly control motor neurons (oculomotor nerve) to affect eye movements or target-directed saccades. Parietal area PG, via its involvement in spatial attention and the frontal eye fields, has a strong influence on this pathway. Attention strongly affects these target-directed saccades. Intrusions by the reflexive peripheral eye systems are inhibited when the frontal eye fields generate targeted eye movements.

The relation of sustained attention to these two eye movement systems involves the "invigorating" aspect of arousal. Attention may operate in a non-selective manner on visual areas, including enhancing form and color discrimination, motion detection and visual tracking, and eye movements. This arousal increases the sensitivity of the "parietal attention system" (Posner & Petersen, 1990) for targeted saccades controlled by the frontal eye fields. The invigorating aspects of the arousal system would aid in the attention-directed focal eye movements, and inhibit peripheral localization. Disengagement of the geniculo-striate-extrastriate-frontal eye field system is necessary before the collicular system will respond by shifting the gaze to a peripheral target (Posner & Presti, 1987). The interrupted stimulus paradigm takes advantage of this relation between the targeted and reflexive saccadic system. As long as sustained attention to the central stimulus occurs, reflexive peripheral localization of the peripheral stimulus cannot occur. Thus, the sustained lowered HR during sustained attention, that is indexing the non-specific arousal system, correlates with the infant's lack of distractibility by the peripheral stimulus.

Developmental changes in sustained attention may be explained by several causes. "Neurodevelopmental" models of these eye movement systems (e.g., Bronson, 1974; Johnson, 1990; Maurer & Lewis, 1979; Richards, 1990a) posit an increasing inhibition of the reflexive peripheral localization system by the attention-directed system from the ages of 2 to 6 months. The reflexive saccadic system is well established at birth. At 2–3 months of age attention-directed targeted saccades, controlled by the posterior attention system and the frontal eye fields, emerge as an important behavior. This brain system (and behavior) develops rapidly and reaches adult characteristics by 5–6 months. Thus, reflexive saccades dominate fixation behavior in the first few months. When the targeted saccadic system begins to emerge, there is an increasing tendency of the attention-directed systems to inhibit intrusive reflexive saccades. Concurrently, from 2 to 6 months of age there are increases in the HR responses during sustained attention, the behavioral differentiation between sustained attention and attention termination, and the corresponding relation between sustained attention and RSA level. The arousal system is developing, the eye movement systems are developing, and there is an increasing synchronicity between these systems in the control of infant behavior during visual attention. Development of visual attention consists of the development of individual systems, and of changing relations between developing systems.

What role does RSA play in this model? The brainstem respiratory centers in the medulla and pons are the primary controllers of RSA. The limbic structures involved in cardiovascular control (e.g., septum, amygdala, hypothalamus) also affect RSA. The connection of this cardiovascular control network to the attention-controlling structures of the frontal cortex, parietal attention system, and mesencephalic reticular formation, may explain why RSA levels correlate with sustained attention. The functional integrity of this entire system may represent the capacity of the infant to respond with widespread neural, physiological, and behavioral responses during attention. The relation between sustained attention, HR responses, and brainstem and cerebral cardiovascular control, suggests that RSA also should index other complex behavioral functions (cf. Porges, this volume). This would be especially true of social, emotional, and personality behaviors that the limbic system controls. Developmental changes in RSA are not merely indexing progressively increasing brainstem effects on HR, but the broad network of CNS structures involved in attention.

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3

Anticipatory Processes in Infants: Cardiac Components

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Relevance of Anticipating

A critical requirement for optimal functioning in any environment is the ability to anticipate, plan, and prepare for important events. Logic and common sense would attest to this, but support is also provided by a wealth of objective evidence confirming that indeed, "forewarned is forearmed." A variety of evidence suggests that this process of anticipation may undergo important developmental changes in the first 6 to 12 months of life. But until recently the supporting data were neither substantial nor unequivocal, in part due to the lack of an optimal paradigm. Within the psychophysiological literature a large body of data on anticipation in adults has been generated. That literature may provide a paradigm that will allow a greater understanding of this cognitive process in infants.

Before proceeding with a discussion on the process of anticipation, it is important to clearly define what we mean by the term. For our purposes, the term *anticipation* is meant to refer to a cognitive process that takes place prior to an event of interest or importance, and is focused on it. Further, under optimal circumstances, anticipation will help the individual to process or enhance positive events, or will help them to handle or provide protection from negative ones. Haith, Hazen, and Goodman (1988) discussed anticipations of "when," "where," or "what." The paradigm and data that we