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The Development of Sustained Attention in Infants

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Attention may be characterized by its selectivity and intensity. The selective aspect of attention narrows the focus of information processing from a wide range of available stimuli, thoughts, and responses to a single aspect of the environment, or a selected set of stimulus-response activities. The intensity aspect of attention improves the quality of information-processing once the information processing focus is narrowed, which results in improvements in the quality of the cognitive activities involved in the attentive behavior. Researchers interested in infant attention have used behavioral measures during toy play to distinguish between periods when attention is intensified, "focused attention," and periods when the infant is inattentive, "casual attention" (Lansink & Richards, 1997; Oakes & Tellinghuisen, 1994; Ruff, 1986; Ruff & Capozzoli, 2003; Ruff & Rothbart, 1997). These behavioral measures, however, are applicable only after infants are capable of manipulating toys (e.g., after 6 months). Psychophysiological measures may be used with young infants as a noninvasive measure of attentiveness. Heart rate (HR) changes to environmental changes also may index periods of attentiveness and inattentiveness in young infants (Graham, 1979; Graham, Anthony, & Ziegler, 1983; Porges, 1976, 1980; Richards, 2001; Richards & Casey, 1991).

One type of attention that may be measured with HR changes is sustained attention. Sustained attention is indicated by a large deceleration of HR and an extended lowered HR. Sustained attention measures the alertness/arousal function of the brain (Richards, 2001). The broad range of influence that the arousal system has on cortical activity is consistent with the role that sustained attention plays in a wide variety of infant cognitive processes. For example, the modulation of blink reflexes by attention, and the development of the modulation, is revealed through measurements of HR-defined sustained attention (Richards, 1998, 2000; see review in Richards, 2001). The characteristics of eye movements and developmental changes in eye movements in young infants are mediated by sustained attention (e.g., Hunter & Richards, 2003; McKinney & Richards, 2004; Richards & Holley, 1999; Richards & Hunter, 1997; see reviews in Richards & Hunter, 1998, 2002). Sustained attention plays an important role in the development of extended looking to television programs in young children (Richards & Anderson, in press; Richards & Cronise, 2000; Richards & Gibson, 1997; Richards & Turner, 2001).

This chapter does two things. First, I review evidence showing how HR may be used as a measure of sustained attention. This section also shows the important changes occurring in sustained attention in the first year. Second, two areas of work are briefly reviewed that show how sustained attention affects infant cognitive processes. The first shows that attention to a central stimulus attenuates infants' responsiveness to peripheral stimuli. The second shows that developmental changes in the event-related potential response to briefly presented stimuli are mediated by infant attentiveness.

HEART RATE CHANGES AS A PSYCHOPHYSIOLOGICAL MEASURE OF INFANT ATTENTION

Infant attention has often been measured with HR. The first use of HR as a measure of attention was motivated by Sokolov's (1963) theory of the orienting reflex. The orienting reflex is the first response of an organism to a stimulus. Sokolov believed that this response was the first sign of a decrease in sensory thresholds and was mediated by peripheral sensory receptivity changes and central brain function activity. This response is composed of behavioral reactions and changes in autonomic nervous system activity. Graham and Clifton (1966) hypothesized that HR deceleration was a component of the orienting reflex and could be used as a sensitive measure of orienting in many species and at several ages.

The first studies of infant attention using HR examined the orienting reflex. Infants over a wide variety of ages were presented with brief (~2 seconds) visual or auditory stimuli and HR was measured. Newborn infants appeared to show only heart rate acceleration to such stimuli, implying that the orienting response did not function well at birth (Chase, 1965; Davis, Crowell, & Chun, 1965; Keen, Chase, & Graham, 1965). Infants were more likely to show heart rate decelerations to such brief stimuli at later ages. Figure 25.1 shows a graph summarizing several studies of the heart rate responses to a 2-second tone as a function of testing age (Graham et al., 1970, 1983). The heart rate deceleration increases in magnitude from birth to 16 weeks of age (about 3 months). This deceleration occurs to a wide variety of auditory, visual, and audiovisual stimuli from this age through the first year of life. The HR responses to such stimuli in adults are dissimilar to that of young infants. Adults show a brief deceleration at the onset of stimulus presentation and show larger HR decelerations only when presented with extended stimuli or in other procedures (e.g., foreperiod of a fixed-foreperiod reaction time task; van der Veen, Lange, van der Molen, Mulder, & Mulder, 2000).

I began my work in the study of HR changes by presenting infants with extended stimulus presentations. The HR changes to briefly presented stimuli represent a subcortically mediated orienting reflex or an automatic interrupt component of attention (Graham, 1979). Although these attention components are interesting and important, the information processing occurring during complex cognitive behavior goes beyond simple stimulus orienting. In one of my first studies I presented infants with complex visual stimuli, such as checkerboards, moving objects, and face-like stimuli (Richards, 1985). The infants in this study were 14, 20, or 26 weeks of age (3, 4½, 6 months). Figure 25.2 presents the HR responses that occurred during uninterrupted looking ("C") or when a peripheral stimulus was presented to distract looking ("S"). The HR change revealed two interesting patterns. First,

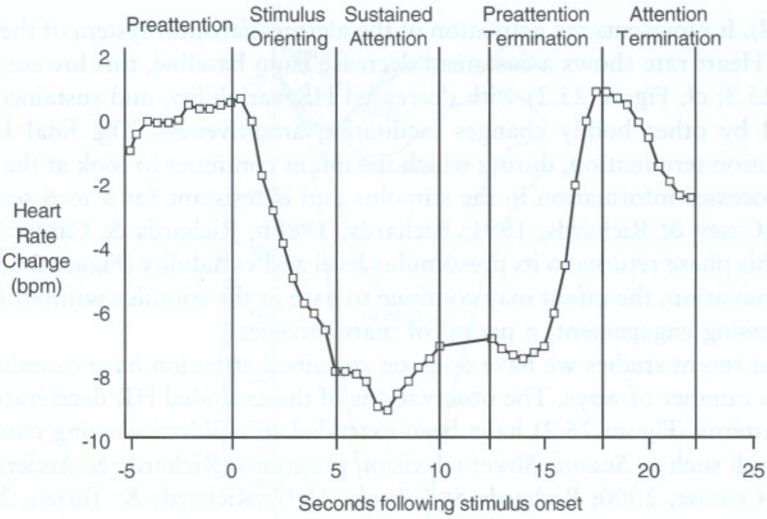

FIGURE 25.3. Average HR change as a function of seconds following stimulus onset during the HR-defined attention phases. Data from Richards and Casey (1991, 1992).

ame Street movie for up to 100 seconds. This figure shows short latency changes associated with short looks, an increasingly sustained HR change for longer looks (40 seconds, "4"), and continued sustained HR change for the extremely long looks (up to 100 seconds, "5"). Complex stimuli extend the HR deceleration change that is found for relatively simple stimuli. As with the response to the brief stimulus presentation (Figure 25.1), adults show a dissimilar pattern of HR changes during sustained attention. At stimulus onset, HR decelerates only briefly and then returns to prestimulus level (e.g., Figure 25.1). Subsequently, adult

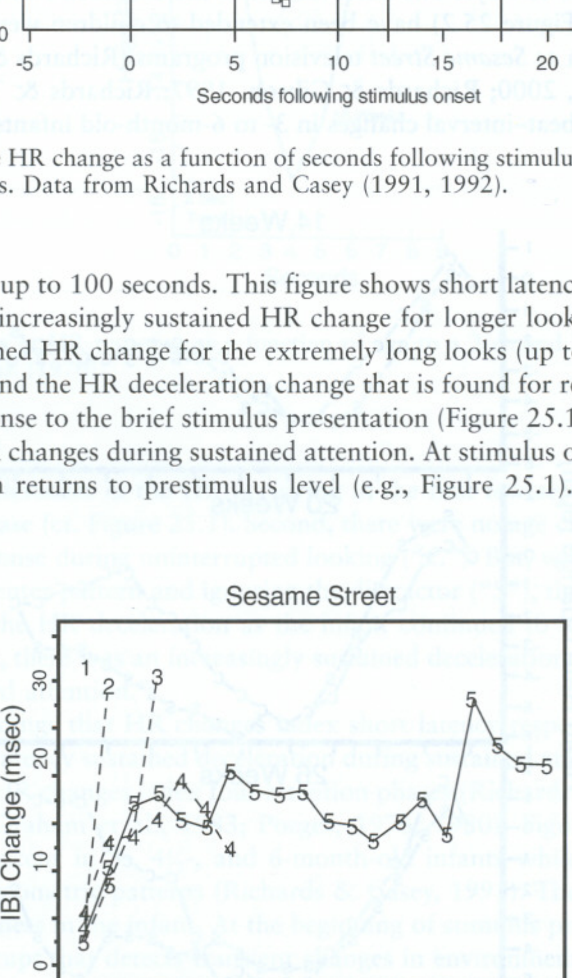

FIGURE 25.4. Increases in interbeat interval (IBI) length (HR deceleration) as a function of the duration of fixation on a *Sesame Street* movie for the same-age infants (Richards & Gibson, 1997). The lines represent IBI changes occurring for looks that lasted 5 seconds ("1"), 6 to 10 seconds ("2"), 11 to 20 seconds ("3"), 21 to 40 seconds ("4"), and greater than 40 seconds ("5").

TABLE 25.1. HR Changes in Attention Phases from 2 to 6 Months of Age and for High- and Low-RSA Infants, and Baseline HR and RSA in Full-Term Infants from 3 to 6 Months of Age

HR changes in attention phases from 2 to 6 months	8 weeks	14 weeks	20 weeks	26 weeks
Stimulus orienting	−3.7	−4.2	−5.2	−4.7
Sustained attention	−6.9	−6.9	−8.5	−11.0
Attention termination	−1.7	−2.8	0.3	0.3

HR changes in attention phases for high- and low-RSA infants	Low RSA	High RSA
Stimulus orienting	−4.8	−5.2
Sustained attention	−7.9	−11.5
Attention termination	−1.3	−0.5

Baseline HR and RSA in full-term infants from 3 to 6 months of age	14 weeks	20 weeks	26 weeks
Baseline HR	152	148	142
Baseline RSA	0.78	0.86	0.92

Note. From Richards (1995). Copyright 1995 by Plenum Press. Adapted by permission.

beat-to-beat HR variability is suppressed during sustained attention in proportion to the intensity of the cognitive processing (Hansen, Johnsen, & Thayer, 2003; Mulder & Mulder, 1981, 1987; Redondo & Del Valle-Inclán, 1992).

We also have studied the development of sustained attention and heart rate changes in a number of studies. Table 25.1 contains the mean HR changes during attention compiled from a number of studies. There is an increase in the level of the HR deceleration in response to interesting stimuli from 8 weeks to 26 weeks of age. This increase is accompanied by decreasing levels of resting HR and increasing levels of respiratory sinus arrhythmia (RSA), both of which reflect developmental changes in cardiovascular control (Bar-Haim, Marshall, & Fox, 2000; Frick & Richards, 2001; Harper, Hoppenbrowers, Sterman, McGinty, & Hodgman, 1976; Harper et al., 1978; Katona, Frasz, & Egbert, 1980; Richards, 1985, 1987; Richards & Casey, 1991; Watanabe, Iwase, & Hara, 1973).

Several studies in my laboratory have investigated the characteristics of these attention phases, focusing primarily on the development of sustained attention. My colleagues and I have reviewed these studies in several places (Reynolds & Richards, in press; Richards, 1988a, 1995, 2001, 2002, in press; Richards & Anderson, in press; Richards & Casey, 1992; Richards & Hunter, 1998, 2002; Richards & Lansink, 1998). In the rest of the chapter I focus on two areas of work showing the role that sustained attention plays in infant behavior.

SUSTAINED ATTENTION AND PERIPHERAL STIMULUS RESPONSIVITY

The first area of work that I review are studies demonstrating that infants presented with stimuli in focal stimulus locations will be less likely to shift fixation to peripheral stimuli (see Richards & Lansink, 1998). The first interpretations of this work suggested that central stimuli restrict the infant's visual field. The most recent work has shown that it is only when central stimuli engage infant attention that peripheral stimulus localization is attenuated.

The first studies of infant's response to visual stimuli presented in the periphery were done to determine the extent of the visual field with "localization perimetry" (Aslin & Salapatek, 1975; de Schonen, McKenzie, Maury, & Bresson, 1978; Harris & MacFarlane, 1974; MacFarlane, Harris, & Barnes, 1976; Tronick, 1972; see review by Maurer & Lewis, 1998). Localization perimetry defined the infant's effective visual field as the eccentricity at which an infant will shift fixation from a center location to a peripheral location. A procedure used in these early studies was to attract the infant's fixation to the central visual field with a stimulus in the center of the visual field. If the stimulus in the center was left on, the "effective visual field" seemed to decrease. One- and 2-month old infants, for example, make directionally appropriate eye movements toward a peripheral stimulus at 40 degrees more than 50% of the time without a central stimulus, but less than 20% of the time in the focal central stimulus's presence (e.g., Aslin & Salapatek, 1975). The focal stimulus' presence increases the latency to make a directionally appropriate eye movement if the focal stimulus remains on long enough for the infant to make an eye movement to the peripheral stimulus (Aslin & Salapatek, 1975; Atkinson, Hood, Braddick, & Wattam-Bell, 1988; Atkinson, Hood, Wattam-Bell, & Braddick, 1992; Hood & Atkinson, 1993; Richards, 1987, 1997b).

The best interpretation of these results is that attention to the central stimulus is the cause of the attenuation of peripheral stimulus localization. Finlay and Ivinskis (1982, 1984, 1987) and Richards (1987, 1997b) have interpreted the longer latencies to shift fixation toward the peripheral stimulus as an indication of the attention level to the central stimulus. In this interpretation, the presence of a central stimulus engages attention. As long as attention to the center stimulus is occurring, there is decreased responsiveness to the peripheral stimulus. In contrast, at times infants will continue to look at the center stimulus in the absence of active attention engagement. In this case, localization percentage of a fixed-duration peripheral stimulus is likely (Finlay & Ivinskis, 1982, 1984, 1987; Hunter & Richards, 2003; Richards, 1997b; Richards & Hunter, 1997), or localization of a continuing stimulus occurs quickly (Richards, 1987). Focal stimulus attention results in a spatial selectivity for fixation, with fixation being directed primarily toward the location in which the attended stimulus occurs.

The role of attentiveness on infant peripheral stimulus localization is illustrated by a study of infants of 14, 20, and 26 weeks of age (Richards, 1997b). The infants were presented with interesting visual stimuli in the center. These stimuli were known to elicit HR changes such as those shown in Figure 25.3. A small peripheral stimulus was presented for 2 seconds. The dependent variable for the study was whether the infant looked toward the peripheral stimulus when it was presented and localization percentage (hits) was calculated. The peripheral stimuli were presented at delays from the onset of the center pattern defined by fixed time intervals (e.g., 2 seconds after stimulus onset, 4 seconds after stimulus onset) or by changes in HR (e.g., significant HR deceleration and return of HR to prestimulus level). Thus, the probability of localizing the peripheral stimulus when it was presented could be examined either by the fixed delays or by delays defined by HR changes.

Figure 25.5 shows some results from this study. This figure shows the percentage of localization of the peripheral stimulus as a function of the delays. The "Prestim" condition was the peripheral stimulus presented before the center stimulus—that is, the baseline level of localization for this peripheral stimulus (about 82%). The "Immed" delay was a presen-

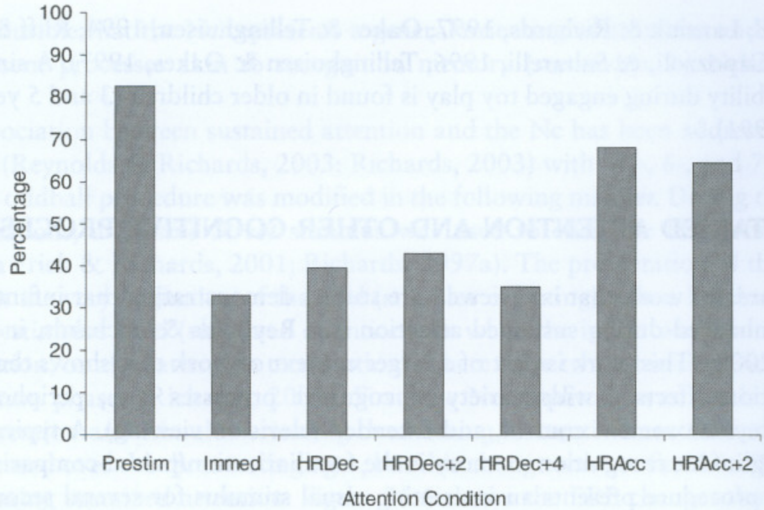

FIGURE 25.5. Percentages of peripheral stimulus localization as a function of the HR changes occurring during distractor presentations. No central stimulus was present during the prestimulus period (Prestim). The immediate period (Immed) refers to stimulus onset. Sustained attention coincides with all of the HR deceleration periods (HRDec), and attention termination is represented by HR accelerations (HRAcc).

tation of the peripheral stimulus about 100 msec following the central stimulus, the "HRDec" (HRDec, HRDec + 2 seconds, HRDec + 4 seconds) delays were defined by the occurrence of a deceleration in HR following by 0, 2, or 4 seconds, and the "HRReturn" (HRReturn, HRReturn + 2) delays were defined as occurring when HR returned to its prestimulus level. The immediate and HR deceleration conditions represent a period when sustained attention is directed toward the central pattern. These resulted in a very low percentage of localization. The return of HR to its prestimulus level represented a period of inattentiveness, even though the infants continued to look toward the central stimulus. When the peripheral stimulus was presented it was localized more frequently in this condition. When infants show by sustained lowered HR that sustained attention to the central stimulus is engaged, a peripheral stimulus presented for a fixed interval is missed (cf. Finlay & Ivinskis, 1984), or the latency to localize a continuing peripheral stimulus is very long (Richards, 1987). Unresponsiveness to the peripheral stimulus indicates an enhanced attention level for the central stimulus. In contrast, when infants show by lack of a significant HR response that attention is not engaged, then a stimulus presented for a fixed interval is more likely to be localized, or localized with a shorter latency than during sustained attention.

The effect of attention on peripheral stimulus localization is general across a wide range of testing situations, testing ages, and measures of attentiveness (Richards & Lansink, 1998). For example, young children age 6, 12, 18, or 24 months when engaged in viewing television programs will be less likely to look away toward peripheral events when showing HR or behavioral signs of attentiveness (Richards & Turner, 2001). This is true also for older-age children (e.g., 3 to 5 years) when watching television programs (Anderson, Choi, & Lorch, 1987; Lorch & Castle, 1997). Infants playing with small toys during periods showing facial expressions consistent with focused attention will continue to look toward and play with the toys, compared to periods when they do not show attentiveness (Doolittle

& Ruff, 1998; Lansink & Richards, 1997; Oakes & Tellinghuisen, 1994; Ruff & Capozzoli, 2003; Ruff, Capozzoli, & Saltarelli, 1996; Tellinghuisen & Oakes, 1997). A similar pattern of indistractibility during engaged toy play is found in older children (3 and 5 years; Choi & Anderson, 1991).

SUSTAINED ATTENTION AND OTHER COGNITIVE PROCESSES

The second area of work that is reviewed are studies demonstrating that infant recognition memory is enhanced during sustained attention (see Reynolds & Richards, in press; Richards, 2001, 2002). This work is part of a larger context of work that shows that infant sustained attention affects a wide variety of cognitive processes (e.g., peripheral stimulus responsivity, eye movement control, and extended television viewing). A typical procedure for measuring infant recognition memory is the familiarization/paired-comparison test procedure. This procedure presents an interesting visual stimulus for several seconds until the infant is familiar with it. Following familiarization, the infant is presented with the exposed stimulus and a novel stimulus not previously seen. A novelty preference indicates recognition of the familiar stimulus.

Several studies have shown the role that sustained attention plays in this procedure. Richards (1997a; also see Frick & Richards, 2001) presented infants between 3 and 6 months of age with a *Sesame Street* video that elicited the HR-defined attention phases (Figure 25.3). The infants were exposed to the familiarization stimulus for only 5 seconds during stimulus orienting, sustained attention, and attention termination, or 5 seconds following attention termination. Following the exposure, a paired-comparison test procedure was done. Trials on which the familiarization stimulus was presented during sustained attention resulted in a significant novelty preference for 20- and 26-week-old infants. Trials on which the familiar stimulus was presented 5 seconds after attention termination and HR had significantly decelerated again (reengaged sustained attention) also resulted in a significant novelty preference. Novelty preference on these two trials types was at similar levels to a 20-second accumulated fixation familiarization trial, a procedure commonly used in research studies using the paired-comparison method. The younger infants, and all infants presented with the familiar stimulus during stimulus orienting or attention termination, did not show the novelty preference. Thus, familiarization during sustained attention results in greater levels of recognition memory than during inattentiveness. The results for the different ages in this procedure show the increasing level of sustained attention across this age range. Other studies have shown similar roles that sustained attention plays in the familiarization and test phases of this infant recognition memory procedure (Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001; Frick & Richards, 2001; Maikranz, Colombo, Richman, & Frick, 2000; Richards & Casey, 1990).

Another procedure that has been used to show the effect of sustained attention on recognition memory is a modified oddball procedure and the measurement of scalp-recorded event-related potentials (ERPs). The "oddball" procedure has been used in adults to measure response to low-probability stimuli, particularly the P300 (P3). This procedure presents a standard stimulus repeatedly and frequently and occasionally presents an "oddball" stimulus. The P300 amplitude is larger to the oddball than to the standard stimulus. This procedure was first tested in infants by Courchesne (1977, 1978). He found a large negative ERP component occurring about 400–800 msec after stimulus onset located primarily in the frontal and central electroencephalographic (EEG) leads, labeled the "Nc" (Negative central). It is plausible that the Nc represents a general orienting of attention and the late slow waves represent processes akin to recognition memory (see review by Nelson & Monk, 2001).

The association between sustained attention and the Nc has been addressed in two recent studies (Reynolds & Richards, 2003; Richards, 2003) with 4½-, 6-, and 7½-month-old infants. The oddball procedure was modified in the following manner. During the brief stimulus presentations, a *Sesame Street* stimulus was used to elicit the HR-defined attention phases (as in Frick & Richards, 2001; Richards, 1997a). The presentation of the test stimuli were done at the very beginning of the trial (stimulus orienting), when HR had decelerated below its prestimulus level (sustained attention), or when the infant was inattentive (attention termination, or after attention termination). There were two interesting findings related to the attention phases (Richards, 2003). First, the Nc amplitude was much larger during sustained attention and stimulus orienting than during inattentiveness. Second, the Nc amplitude increased over the three testing ages, but this change was confined to ERP amplitude measured during sustained attention. Figure 25.6 shows the ERP changes during attention separately for the infants age 4½, 6, or 7 months. The ERP changes (left panels, Fz and Cz) showed an increasing level of the negative ERP response over the three testing ages at about 500–600 msec following stimulus onset (i.e., the Nc). The topographical maps show the Nc at the maximal response. A clear increase occurred over the three testing ages in the magnitude and extent of the Nc. These age differences suggest that the developmental changes in sustained attention known to occur over this age are shown in the Nc and suggest that the Nc is predominantly an indicator of the cortical processes involved in stimulus orienting and arousal. The changes in the Nc over these testing ages reflects developmental changes in sustained attention rather than changes in recognition memory or associated memory processes.

The most recent work we are doing (Reynolds & Richards, 2003) uses high-density (124 channel) EEG recordings. This study involves the estimation of cortical sources of the ERP data with equivalent current dipole analysis. Preliminary findings indicate that the cor-

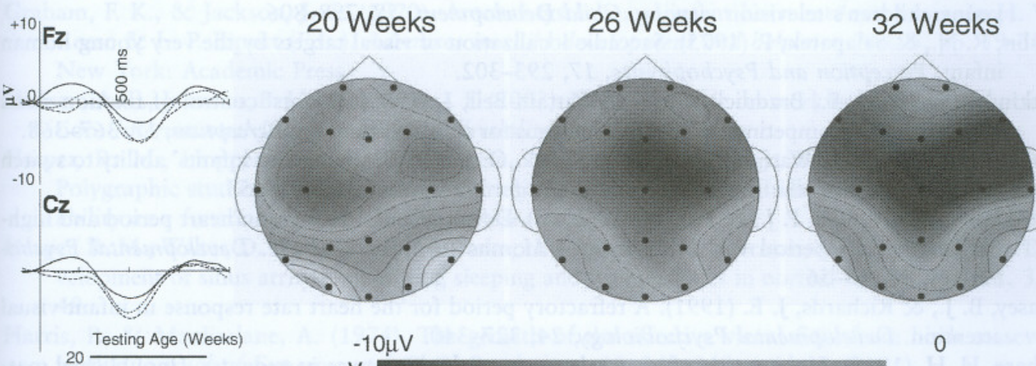

FIGURE 25.6. Development of the Nc component during attention. The ERP recording from 100 msec prior to stimulus onset through 1 second following stimulus onset is shown for the Fz and Cz electrodes for attentive (top figures) and inattentive (bottom figures) periods, separately for the three testing ages. The topographical maps represent an 80-msec average of the ERP for the Nc component at the maximum point of the ERP response. From Richards (2003). Copyright 2003 by Blackwell. Reprinted by permission.

tical source of the Nc component is in areas of prefrontal cortex including the anterior cingulate. This implies that the prefrontal cortex may mediate initial stimulus responsivity in young infants. This finding is consistent with some recent work with adults (Critchley et al., 2003). This work showed that changes in HR variability in adults during cognitive tasks involving controlled processing were closely associated with functional magnetic resonance imaging activity located in the anterior cingulate cortex. A decrease in HR variability is the primary indicator of sustained attention in adult participants (Hansen et al., 2003; Mulder & Mulder, 1981, 1987; Redondo & del Valle-Inclán, 1992).

SUMMARY AND CONCLUSION

The chapter has reviewed work showing that sustained attention may be measured in young infants with HR, that sustained attention develops in the first few months of infancy, and that several cognitive processes in young infants are enhanced by sustained attention. The intensity aspect of attention represents the enhancement of cognitive processing that occurs when alertness and arousal are functioning. Sustained attention in young infants represents this type of arousal and thus enhances processes selected by attention resulting in improvements in infant cognitive processing.

ACKNOWLEDGMENT

This research was supported by Grant No. R01-HD18942 from the National Institute of Child Health and Human Development.

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