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Attention Across Time in Infant Development

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The process of reacting to the events transpiring in our environment is a complex one, oftentimes involving a sequence of steps. For example, the initial response to a stimulus must involve determining the type of attentive response to make: orienting versus defensive response, or selective versus nonselective attention. Once initial decisions are made, additional analyses of the stimulus events may occur, and these are influenced not only by the continuing stimulus events, but also by the outcome of previous response processing decisions. The result is that the process of reacting to events is the sequencing of a set of responses over time. A common circumstance is for later responses to be altered as a result of information gathered in the initial analysis. The evidence is growing that infants demonstrate such contingently programmed sequences of analysis, but that these behaviors undergo developmental changes in the first months of life. It is our purpose to illustrate these results, particularly as they are evidenced in the relation between cardiac activity and cognitive development.

Prior to the middle 1960s, infancy researchers employing a variety of response measures found little reason to segregate attention into components (e.g., Fantz, 1963). A careful dissection of infants' attentional capabilities into component processes was undertaken seriously by Graham and colleagues (e.g., Graham & Clifton, 1966; Graham et al., 1970). The work of Sokolov (e.g., Sokolov, 1963; Sokolov & Cacioppo, chapter 1, this volume) and of the Laceys (e.g., Lacey, Kagan, Lacey, & Moss, 1962) with adults had led Graham to conclude that physiological measures, especially heart rate, may be powerful tools in examining attention in the infant. More important, physiological measures may distinguish attentional processes such as the orienting response from other activation reactions such as defense responses (Graham & Clifton, 1966). This was critical in understanding that the developmental shift from the predominantly accelerative heart rate response of the neonate to the predominantly decelerative response of the older infant could be understood in terms of the infant's defensive and orienting reactions. This interpretation became widely accepted after a priori predictions arising from the Graham and Clifton (1966) hypotheses were empirically supported (e.g., Berg, Berg, & Graham, 1971). This finding was powerful evidence of the value of examining components of attention during the infancy period. It showed that the heart rate response was an important index of such differential stimulus processing in the infant. It provided unequivocal evidence that heart rate responses could be vital for understanding fundamental attention and cognitive mechanisms in early life.

THE SEQUENCE OF ATTENTIONAL RESPONDING: DEVELOPMENTAL CHANGES IN CARDIAC COMPONENTS

In addition to the orienting and defense response distinction, the later work from Graham's laboratory led to the notion that infants' heart rate may also index a sequence of qualitatively differing aspects of information processing that is initiated by stimulus onset and is maintained by a continuation of that ongoing event. In this section we provide an overview of the sequence of processing events suggested by the cardiac results and the indications of their developmental change. Subsequent sections detail two of the more recently investigated processing stages, sustained attention and anticipation.

The first component of the information processing sequence evident in cardiac responses is a very brief deceleration usually in response to a transient stimulus (Berg & Berg, 1987). This response was argued to represent a simple reaction to an onset of the stimulus, a response that did not involve the more elaborate evaluation of the stimulus implied by orienting. Graham (1992) developed a similar concept that she identified as a transient-detecting reaction. Depending on the stimulus intensity, this response might be expressed as a startle reflex or a nonstartle response such as the brief deceleration. Although this transient-detecting response is often considered preattentive, it involves some basic information processing and might be considered as part of an *automatic interrupt system* that at least momentarily disengages the infant from the

stimuli currently undergoing processing and prepares the infant for subsequent processing (Graham, 1979, 1992; Graham, Anthony, & Ziegler, 1983). One element of this response may be to direct attentional mechanisms to the critical part of the sensory space.

Once this is accomplished by the preattentive process, the initial stimulus processing begins. The 2-month-old infant shows a large heart rate deceleration following the shift of fixation (or shift of attention) to a new stimulus, that is, the stimulus orienting response. The sequence from attention getting (i.e., transient detecting) to stimulus orienting was well laid out by Graham in her work. The cardiac result of this next step in processing was a longer lasting deceleration that either replaced or was merged with the brief deceleration indicative of transient detection. The orienting differed not only in form and duration from the automatic interrupt system, but had as its function the initial stimulus processing and, as such, could well be related to cortical functioning. Although the longer deceleration associated with orienting was difficult to elicit prior to about 2 months of age, the neonate readily elicited the brief deceleration suggestive of the interrupt response (Berg & Berg, 1987). This change from the transient to the longer decelerative response during in the first month or two of life reflects a maturational shift from the simple initial reaction to the two-step sequence of stimulus handling of interrupt followed quickly by orienting.

Models of heart rate change in infants have extended heart rate's utility as an index of attention processes even further in time. Both Porges (1976, 1980) and Richards (1988; Richards & Casey, 1992) postulated that *sustained attention* an additional process that follows orienting. Richards, among others (Ruff, 1986), hypothesized that this later attention phase is one in which the orienting to the stimulus is maintained or amplified in order to process information in the stimulus. It is during this attention phase that information acquisition occurs. Sustained attention normally incorporates two aspects of attention: intensive and selective attention. The selective nature of attention is represented by the narrowing of information processing to a single object, idea, or behavior. The intensive aspect of attention is concerned with the effects that attention engagement has on the task, leading to increased processing efficiency, shortened reaction times and so forth. Both aspects have long been recognized, being suggested even by James (1890). In a well-known quotation James indicated: "Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought . . ." (pp. 403–404). He further noted, "The immediate effects of attention are to make us: a) perceive, b) conceive, c) distinguish, d) shorten reaction time . . . better than otherwise we could . . ." (pp. 424–425).

The role of selective attention can be evidenced in different ways. In visual processing, for example, selective attention directs one's focus toward a specific location or object in the visual field. Further, selective attention inhibits one's focus toward the parts of the visual field that are not selected. A preattentive system controls this early part of this process. Cohen (1972, 1973) investigated just such a process, denoting as "attention-getting." However, this might be better labeled *receptor-getting* rather than attention-getting, because the primary function is to direct receptors in a manner to optimally sense the stimulus. Cohen (1972, 1973) also developed the notion of *attention-holding*, an aspect of selectivity that controls the duration of attention. This occurs more or less simultaneously with attention's intensive aspect. Later in this chapter we show that developmental changes in attention between 2 and 6 months of age occur primarily in this aspect of attention.

The attentional processes described thus far function to assess the eliciting stimulus, its ongoing qualities, and its immediate implications. However, past experience with the consequences of the current stimulus may allow prediction of events to follow. In this circumstance the attentional process adds a new dimension—the anticipatory response. This future-oriented system might either overlap the sustained attention to the predictive stimulus or develop out of this experience. In its most elaborate form, the anticipatory response represents some type of planning or executive control of behavior and may reflect frontal lobe activity. As such it demands the integration of several simple attention systems in order for the infant to execute specific actions (see Posner, Rothbart, & Gerardi, chapter 14, this volume). The final sections of the chapter review evidence that infants 3 months of age are just beginning to demonstrate this anticipatory behavior (Haith, Hazan, & Goodman, 1988) and it is not readily seen as part of the cardiac response until 4 months or older (Boswell, Garner, & Berg, 1994; Donohue & Berg, 1991; see also Berg & Donohue, 1992).

The picture that emerges from this brief overview is that attention, as reflected in cardiac activity, involves a distinct sequence of processing events. In its most elaborate form, a signal would initially elicit an interruption of ongoing activity, an initial determination of the basic attentional process to be engaged, and a preliminary orientation of receptors. Following this preattentive action, a more elaborate orientation process would be engaged and if the signal were found to be of sufficient interest, this process would be sustained. Provided that past experience with the signal indicates other events of importance would reliably follow, there would then be a shift to focusing on the implications of these events (anticipation), and possibly actions would then be engaged that would help plan or prepare for them. Evidence suggests that the ability to produce fully this sequence of attentional processing develops gradually over at least the first 6 months of life. This development progresses from the preattentional processes available at birth, to maturation of orienting, to expression of sustained attention and anticipation. The next sections focus on these latter two processes, which have received much less attention among investigators examining infant cognition.

SUSTAINED ATTENTION: THE SELECTIVE ASPECTS

The use of heart rate as an attention index in the early work of Graham and her colleagues was limited to the early preattentive responses and the stimulus orienting response. If stimulus presentation is sustained and the infant continues attending, the heart rate continues to be sustained below the prestimulus level. Figure 15.1 shows the responses of infants at 14, 20, and 26 weeks of age while viewing a central visual stimulus (Richards, 1985). In that study there were trials with a single stimulus (C line in Fig. 15.1) and trials with a competing visual stimulus in the periphery (S line in Fig. 15.1). The central stimulus in both trial types resulted in the typical heart rate deceleration in the first 4 to 5 sec characterizing stimulus orienting. The single stimulus trials included heart rate responses during active attention to the stimulus along with heart rate changes when the infant was no longer interested in the stimulus but would not shift fixation because there was no other stimulus to look at. In the condition with the competing stimulus, the heart rate response displayed in Fig. 15.1 includes only that period of time when the infant selected the central stimulus and did not localize the peripheral stimulus. The continued fixation on the central stimulus implies that the infant was still engaged in active information processing of the central stimulus. During that time, the heart rate response remained below the prestimulus level as long as the infant continued to look at the central stimulus, particularly for the two older age groups. This later attention phase, occurring after the first 4 to 5 sec, has been labeled *sustained attention* (Richards & Casey, 1991, 1992).

An important finding coming from that study is the developmental change implied by the response shown in Fig. 15.1. Stimulus orienting does not seem to show much change over this age range, whereas the sustained heart rate response during sustained attention increases. This suggests a major shift in attention over this age range. A major development shift emphasized in Graham's work was the change from the early heart rate response in the neonate to the stimulus orienting response in the 6- to 8-week-old infant. Given the results presented in Fig. 15.1 and subsequently verified in further research (see Richards & Casey, 1992), it

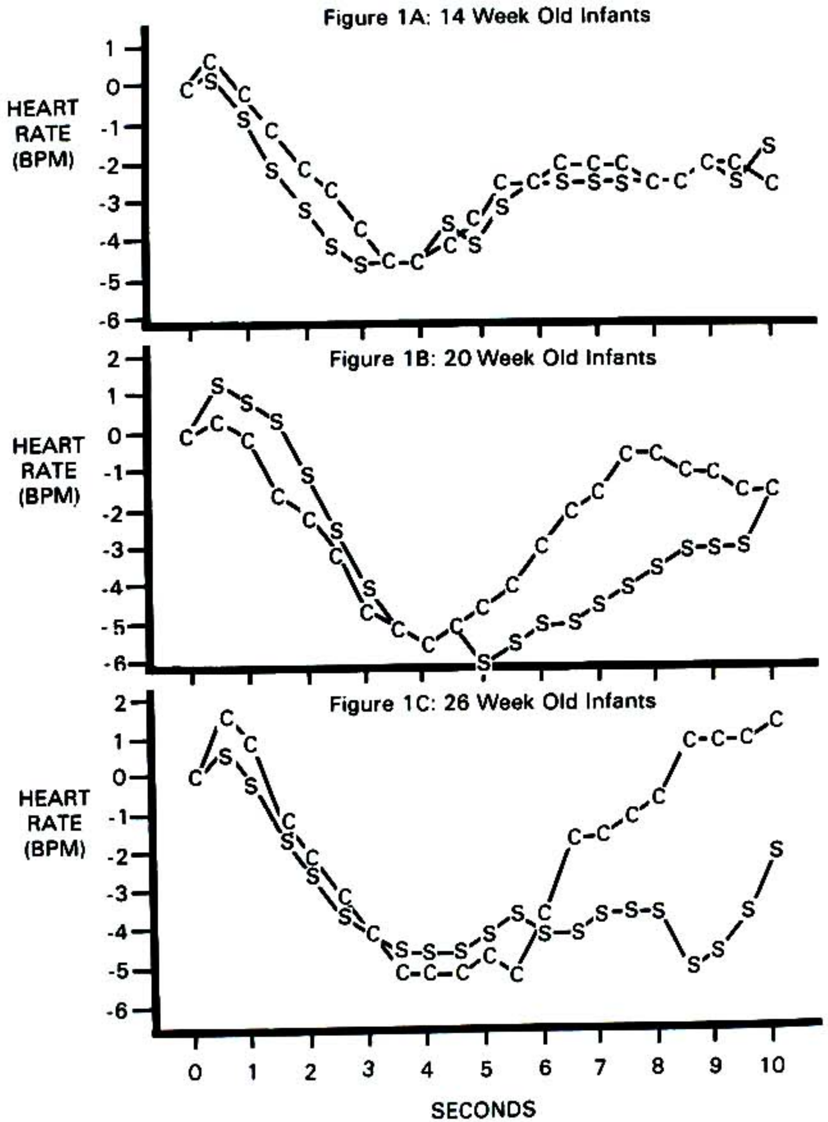

FIG. 15.1. Average heart rate change for infants while viewing a central stimulus presented alone (Infant Control, C) or viewing a central stimulus in the presence of a competing peripheral stimulus (Interrupted Stimulus, S). From Richards (1985). Reprinted with permission.

appears that after 6 to 8 weeks, the stimulus orienting attention phase shows little change. It is the sustained aspect of attention that changes over this age range.

Sustained attention's selective nature has been emphasized in a series of studies by Richards and colleagues. In these studies, infants are presented with an interesting central visual stimulus that elicits stimulus orienting and sustained attention heart rate responses. After a delay from the onset of the central stimulus, a peripheral stimulus is presented in an attempt to interrupt the infant's fixation on the central stimulus. The delay is defined by evaluating the ongoing heart rate activity and presenting the interrupting stimulus contingent on the heart rate response pattern. For example, the *sustained attention* delay is defined as when heart rate has decelerated below its prestimulus level and has sustained lowering. *Attention termination* is defined as the heart rate returning to its prestimulus level following sustained attention. This a priori selection of sustained attention and attention termination by online evaluation of the heart rate response provides experimental control over the presence or absence of attention. As a control for the simple passage of time, the delay may be defined at specific time intervals (e.g., 3, 7, 10 sec) and attention is evaluated by the ongoing heart rate response at the time of the delay.

These studies provide firm support that the period of time defined by sustained heart rate responding is selective in directing fixation. For example, in one study (Richards, 1987) the peripheral stimulus remained on until the infant looked toward it. Infants took 6.58 sec before redirecting fixation to the peripheral stimulus in the sustained attention trials and 3.29 sec in the attention termination trials. If the interrupting stimulus remained on only for a fixed duration (e.g., 2 sec), infants between 3 and 6 months localized the peripheral stimulus only 40% of the time during sustained attention to the central stimulus, more than 60% of the time during attention termination, and nearly 85% of the time when no central stimulus is present (Richards, 1995b). Sustained attention, defined by the heart rate response, focuses fixation toward the object of interest and attenuates object localization in other locations.

The *interrupted stimulus* method has revealed an interesting relation between heart rate response, behavioral response, and the need for psychophysiological methods to examine infant selective attention. In visual fixation studies a stimulus is typically presented until the infant looks away from it. The measure of attention is the duration of fixation on the stimulus. However, in many situations the infant will continue to fixate the stimulus long after attention to it has waned. Thus, the behavioral measure of attention, fixation duration, may include both attentive and inattentive periods. The heart rate responses to a single stimulus (C in Fig. 15.1) show that heart rate will return to prestimulus levels even though fixation continues, presumably indicating that the infant is no longer interested in the stimulus. The use of the competing peripheral stimulus to interrupt fixation at the time that sustained attention or attention termination is hypothesized to be occurring reveals the ease with which fixation is redirected during heart-rate-defined attention termination, and the difficulty of redirecting fixation during sustained attention. It is the combination of behavioral measures, physiological responses, and psychophysiological techniques that reveals this selective aspect of attention.

Thus, heart rate changes during fixation to continued stimuli involve both the early heart rate changes due to the *automatic interrupt* and to stimulus orienting, and a further phase of sustained lowering that has been labeled *sustained attention*. Development after 2 months of age in the heart rate response occurs primarily in this later attention phase. This later attention phase is strongly selective; that is, during visual attention, fixation is directed toward the stimulus of interest and stimuli in other parts of the visual field are not readily localized.

SUSTAINED ATTENTION: THE INTENSIVE ASPECTS

Sustained attention's intensive aspect has also been shown in infant attention. Again, sustained attention is defined by heart rate changes that occur in response to stimuli. The initial heart rate deceleration (Fig. 15.1) defines stimulus orienting, the sustained heart rate lowering (Fig. 15.1) defines sustained attention and the return of heart rate to its prestimulus level defines a period of time in which attention to the stimulus has waned even though the infant may continue to fixate on the stimulus. The models of sustained attention (e.g., Richards & Casey, 1992) posit that during this period of time, there is enhanced information processing relative to attention termination and perhaps, stimulus orienting.

Selective attention's intensive aspect has been tested in two recent studies. In one study (Richards, 1995a), it was hypothesized that infants are engaged in intensive information processing during sustained attention. Therefore, information presented during sustained attention should affect later behavior more strongly than information presented during stimulus orienting or attention termination. This was examined by eliciting heart rate changes with a Sesame Street movie, *Follow That Bird*, in infants at 14, 20, or 26 weeks of age. Scenes from this movie result in deep and sustained heart rate decelerations in young infants. The Sesame Street movie was presented until appropriate attention phases were reached. Then, a computer-generated familiarization stimulus was presented that lasted for 2.5 or 5.0 sec. The familiarization stimulus was presented either in sustained attention or attention termination. Recognition memory for the briefly presented visual stimulus was measured by testing novelty preference in a subsequent paired-comparison test phase paradigm. The paired-comparison procedure involves a presentation of a stimulus to which the infant has already been exposed and a novel stimulus previously unseen. Preference for the novel stimulus (extended looking time) in the test phase indicates that the infant recognizes the previously seen stimulus.

This study's results demonstrate sustained attention's intensive aspect. For stimuli presented during attention termination (heart rate return to prestimulus level) in the familiarization phase, the infant's preference for the novel stimulus (and presumed familiar stimulus recognition) in the subsequent test phase was at the same level as it was in the test phase of a no familiarization control trial in which the infant was exposed to neither of the paired-comparison stimuli in the familiarization phase. In contrast, for the familiarization stimulus presented during sustained attention (heart rate deceleration), infants fixated on the novel stimulus in the subsequent test phase much longer than the stimulus to which they were previously exposed and longer on the novel stimulus than during the test phase of the no familiarization control condition.

A very interesting finding in that study was that exposure for 5 sec to the familiarization stimulus during sustained attention was as effective in modifying novelty preference as was exposure for 20 sec when the attention phases were uncontrolled. There was a positive linear relation between the stimulus exposure duration during sustained attention in the familiarization phase and the subsequent recognition memory. Trials with only 1 to 2 sec of exposure time in sustained attention resulted in familiar and novel stimulus fixation durations that were not different from no-exposure control conditions. Trials with 2 to 3 sec, or 4 to 5 sec of exposure in sustained attention, resulted in novelty preference scores that were not different from those found in a 20-sec exposure trial! The typical 20-sec or 30-sec stimulus exposure given for such paired-comparison recognition-memory procedures may consist of only 5 to 10 sec of sustained attention. This study's results imply that it is stimulus exposure during sustained attention that is correlated with subsequent novelty preference, rather than the stimulus exposure per se.

A second study in which sustained attention's intensive aspect was examined was inspired by results from Anthony and Graham (1983). In their investigation, attention engagement was elicited by presenting "interesting" or "dull" visual or auditory stimuli to 16-week-old infants. The interesting stimuli were complex visual patterns or sounds that elicited heart rate deceleration. The dull stimuli were a simple light or tone and resulted in smaller heart rate deceleration than the interesting stimuli.

Following a 4-sec delay, a visual or auditory probe that was known to elicit a blink reflex was presented. The blink reflex was enhanced in magnitude when attention was the greatest (interesting vs. dull) and when the blink probe and the foreground stimulus were in the same modality (match vs. mismatch). Given that sustained attention was engaged at 4 sec, these results imply that the blink probe stimulus in the interesting, same modality condition was processed more effectively (larger blink magnitude) than during the matched, dull foreground, or the mismatched stimulus. The relative enhancement or attenuation of the blink reflex for stimuli in the matched or mismatched modalities is evidence for selective modality attention effects early in infancy.

A recent study by Richards (1994) followed up this finding with a priori definitions of sustained attention and attention termination and extended the ages that were tested from 8 to 26 weeks of age. This study used the same modality conditions as the Anthony and Graham study—a visual foreground and visual probe (match), a visual foreground and auditory probe (mismatch), an auditory foreground and visual probe (mismatch) and an auditory foreground and auditory probe (match). However, instead of presenting different stimulus types (interesting and dull), only "interesting" stimuli were used. The probe stimulus delay, rather than being defined strictly by time as in the Anthony and Graham study, was defined by the presence of heart rate deceleration (sustained attention) or the return of heart rate to its prestimulus level (attention termination). Thus, attention engagement was experimentally controlled not by different stimuli but by different attention phases to the same stimulus types.

This study's results replicate the Anthony and Graham (1983) study in several respects. For example, Fig. 15.2 shows the Anthony and Graham (1983) and the Richards (1994) results. The reflex blink occurring during the interesting foreground stimulus (Anthony & Graham) or during sustained attention (Richards; hatched bars) was significantly larger than the blink reflex occurring during the dull stimulus (Anthony & Graham) or during attention termination (Richards; solid bars). This was true only for the match conditions, whereas the opposite was true for the mismatch condition. Thus, relative to inattention or attention termination, sustained attention enhances probe stimulus processing in the same modality (selective and intensive) and attenuates processing in the different modality (selective and not intensive).

There was an extremely interesting developmental trend in the selective nature of this response. Only 16-week-old infants were tested in Anthony and Graham (1993). In Richards (1994), infants were tested at 8, 14, 20, and 26 weeks. There was no change over this age range in the absolute magnitude of the blink response to either the auditory or the visual reflex

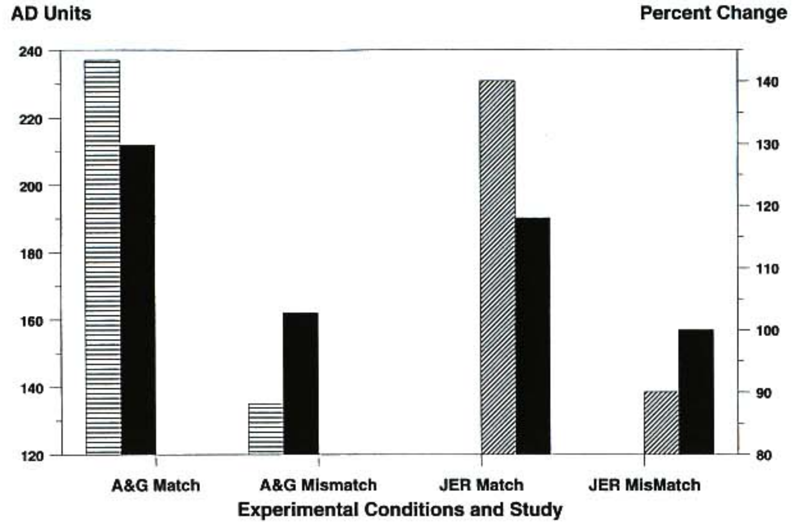

FIG. 15.2. Blink reflexes (A/D units for Anthony & Graham, Percent Change for Richards) as a function of the match between foreground modality and blink reflex stimulus modality, comparison between Anthony and Graham (1983; A&G) and Richards (1994; JER) results. The data is summed over both auditory and visual foregrounds and blink stimuli. The subjects in the Anthony and Graham study were 16 weeks. The subjects in the Richards study were 8, 14, 20, or 26 weeks. Note: Hatched bars—interesting foreground (A&G), sustained attention (JER). Solid bars—dull foreground (A&G), attention termination (JER).

probe when it was presented alone. There was a clear developmental trend in the modality selectivity over this age range. The youngest infants did not show the pattern of match–mismatch probe responses during sustained attention. The oldest infants showed the largest disparity between the match and mismatch conditions, with much larger responses during sustained attention condition relative to attention termination (e.g., the pattern shown across age groups in Fig. 15.2). The 14-week-old and 20-week-old infants showed an intermediate attention-based modality selectivity effect. Anthony and Graham's results with 16-week-olds were intermediate to the 14- and 20-week-olds in the Richards study! Developmental change in sustained attention also increases the "selective" nature of attention such that the chosen sensory modality is intensively processed. The processing of nonselected modalities is attenuated.

The attention phase in the heart rate response called *sustained attention* therefore involves intensive information processing. Recognition memory involves information extraction and inducement of a cognitive representation ("neural model"?). The finding that this occurs with ease during sustained attention, and may be primarily occurring during sustained attention, demonstrates the intensive aspect of sustained attention. Sustained attention also has a top-down influence on processing occurring in simpler response systems. The reflex blink represents both simple preattentive cognitive characteristics and is controlled by subcortical mechanisms. The reflex blink enhancement for the same modality stimulus during sustained attention implies that the intensive aspect of attention may operate by enhancing complementary sensory systems, either peripheral or subcortical in origin. At the same time, sustained attention attenuates competing attention systems, whether they are sensor redirection (shift in fixation) or automatic interrupt responses to stimuli in nonattended modalities. The enhancement of complementary systems for processing (intensive) and the attenuation of competing systems to inhibit their processing (selective) suggests that the selective and intensive aspects of attention listed by James are closely intertwined in sustained attention.

ANTICIPATION: INFANTS' ABILITY TO ATTEND TO THE FUTURE

The selective and intensive processes of sustained attention require that the infant focus on a stimulus that is ongoing or that just previously occurred. That is, they involve attention to events past or present. Attention to present events is also needed for the preattentive and orienting processes elaborated by Graham. In contrast, the focus in this final section is concerned with attention that, hypothetically at least, is focused on events yet to come—on events that the present stimulus may forecast, but that is not yet available. This looking forward to the future is the function of the attentional process of anticipation.

Despite the obvious adaptive significance of the ability to accurately anticipate, plan, and prepare for significant future events and its prominence in behavioral research with adults, there has been little systematic attention paid to its development in either empirical studies or theory. Piaget (1951, 1952) recognized the importance of the ability to anticipate significant events. He argued that this ability did not fully blossom until late in the first year of life, during Stage IV of the sensorimotor period. Although Piaget's theories and concepts have served to stimulate a very wide range of research, research on developmental changes in anticipation has only recently been evident. This is apparent in several laboratories employing a variety of paradigms and response measures (e.g., Berg & Donohue, 1992; Clohessy, Posner, & Rothbart, 1992; Haith, Hazan, & Goodman, 1988; Johnson, Posner, & Rothbart, 1991; Resnick, 1992; see also Siddle and Lipp, chapter 2, this volume).

The cardiac expressions of this process have most often been explored using the paired stimulus, or S1–S2 paradigm. This paradigm is frequently used in experimental psychology research, such as classical conditioning or foreperiod reaction time studies. It is also common in everyday life—for example, traffic lights (yellow light = S1, red light = S2) or the smell of dinner cooking prior to being served. The individual not only attends to each of the S1 stimuli themselves, but also, with repeated pairing, focuses on the upcoming S2 event *prior* to its arrival. That is, we anticipate the event. This anticipation may be highly varied, involving hypotheses as the exact nature of the S2 where this may not be certain ("What's for dinner?"), or preparing to better deal with a highly predictable, specific event when it occurs.

Research with adult subjects suggests that momentary changes in heart rate reflect this anticipatory process very effectively (see Bohlin & Kjellberg, 1979, for a review). The heart rate pattern during the interstimulus interval is basically the same for a variety of types of S1–S2 paradigms: a three component, deceleration-acceleration-deceleration pattern. The brief initial deceleration is a response to S1 onset, but often quickly habituates and therefore may not be evident when responses are shown averaged over many trials. The amplitude of the acceleration may vary from nonexistent to substantial, depending on factors such as the energy requirements of the response to occur (Chase, Graham, & Graham, 1968), stimulus significance (Coles & Duncan-Johnson, 1975), or affective valence (Lang, Ohman, & Simons, 1978), among others. The final deceleration is the most consistently reported of the components. The amplitude will vary with factors such as the salience of S2 and the motivation of the subject to respond (Bohlin & Kjellberg, 1979; Lang et al., 1978). Although there are disagreements as to the precise factors that influence the three components, there is agreement that the components are reasonably independent, being responsive to different stimulus and processing demands. Thus, the heart rate response in the paired-stimulus paradigm provides a rich source of information about anticipation.

The importance of examining the ontogeny of these anticipatory cardiac processes was illustrated in a study of neonates by Clifton (1974). In this study awake, alert neonates were trained for 20 trials. Each trial consisted of an 8-sec tone conditioned stimulus (CS) followed by a 10-sec oral presentation of a glucose unconditioned stimulus (UCS). The UCS onset began 6 sec after CS onset. The glucose and baseline tone presentation readily produced heart rate changes in initial trials. However, there was no significant heart rate response during the tone–glucose (CS–UCS) interval during conditioning trials. On the initial extinction trial substantial deceleration was produced at the point of omission of the glucose for paired but not control subjects. The finding indicated that the infants had developed an association of the two events but did not show signs of anticipation in the cardiac responses. In Clifton's terms, the neonates demonstrated a "What happened?" response, but not a "Here it comes!"

response. Forbes and Porges (1973) reported a similar finding in an aversive conditioning situation using a loud buzzer as a noxious UCS.

There have been claims of successful anticipatory heart rate conditioning in neonates but the results are quite limited (see Berg & Donohue, 1992, for review). Overall, these results and Clifton's careful study demonstrate the apparent difficulty in obtaining an anticipatory heart rate response among neonates. Failure to produce such anticipatory heart rate responding could be attributed to the response system limitations, to lower brain cardiac control mechanisms, or to the cognitive processes modulating the cardiac activity. Evidence points to the latter. Clifton's results clearly demonstrate that in a nonanticipatory condition, the omission of the UCS, the newborn is capable of producing a potent deceleratory response. This deceleration occurs even though decelerations to discrete stimuli in an unpaired-stimulus paradigm are uncommon in neonates. Further, the results point to the specific aspect of the anticipatory process that is not functioning. The inability to anticipate was not a result of an inability to time the CS–UCS interval or to a failure to associate the CS and UCS. These explanations may be rejected because the deceleration occurring on the initial extinction trial began precisely at the point in the trial where the UCS had previously been presented. Instead, the evidence strongly suggests that the lack of an anticipatory heart rate response in this study was specific to the inability to initiate the response prior to the UCS onset.

There is now evidence that anticipatory aspects of the orienting response develop within the first year of life. Donohue and Berg (1991) tested 7-month-old infants, providing a noise for an S1 and, 10 sec thereafter, an interesting, animated mechanical toy for an S2. During the first 12 trials there was no evidence of a late anticipatory deceleration (Fig. 15.3). Thereafter the infants began to demonstrate the anticipatory deceleration, thus seeming to have learned the sequence. This study also demonstrated evidence of orienting to the absence of the toy. On 3 of the 20 trials the toy was omitted and a second wave of heart rate deceleration (one in addition to the anticipatory deceleration) occurred at the point of S2 omission. Because S1 offset did not occur until well after S2 onset, neither this nor any other extant event could provide a cue to the absence of the toy. Infants begin to produce cardiac indicators of anticipation under these test circumstances between birth and 7 months.

A recently completed study has provided information on this transition (Boswell, Garner, & Berg, 1994). Infants 2, 4, and 8 months of age were presented with pairs of stimuli using timing similar to that employed in the Donohue and Berg (1991) study already described. This study differed in that the warning S1 was a bull's-eye plus a tone and the significant S2 was a 3-sec complex video image that moved in synchrony with either music

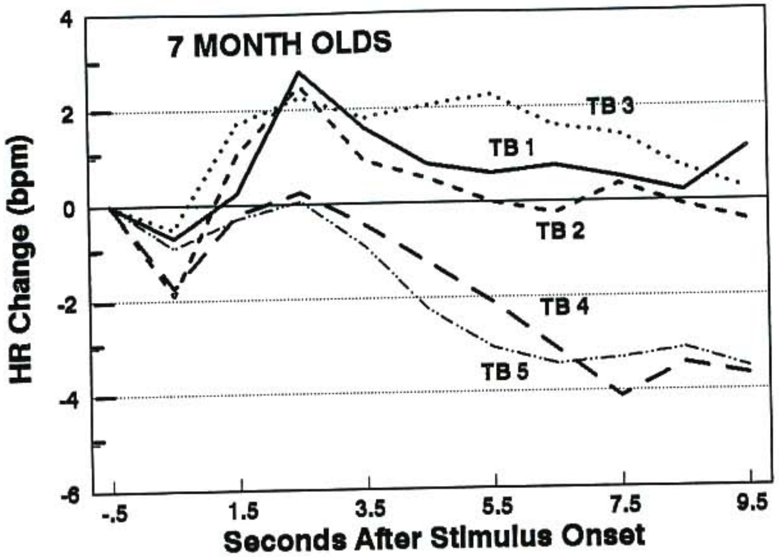

FIG. 15.3. Infant heart rate (HR) over the S1–S2 interval for Trial Blocks (TB) 1–5. (S = stimulus; ISI = interstimulus interval; TB = average of 4 trials each). From Donohue and Berg (1991). Copyright © 1991 by the American Psychological Association. Reprinted with permission.

or a woman speaking in "motherese." Subjects were divided into motorically active and quiet-alert groups based on movement late in the session. The motorically active infants had much more variable and unpredictable heart rate; the quiet-alert infant's responses will be summarized here.

The heart rate response during the S1–S2 interval for 2-month-olds (Fig. 15.4a) was an early deceleration on the initial trial block that habituated with repeated pairings. There was no sign of a late deceleration developing over trials. The first S2 omission produced deceleration virtually as large as to an S2 occurrence on the just prior trial (Fig. 15.5). The reason this response failed to occur on the second S2 omission is not certain, but may be because the trial occurred late in the session when the infant was tiring. However, in Clifton's (1974) results, the deceleratory response to UCS omission was also limited to the first extinction trial so it is possible that infants quickly habituate to the unexpected omission of S2. In this study, the deceleratory response to the first omission was significant when tested alone and did not differ significantly from the response to an actual S2 presentation. We conclude from this that at 2 months of age, as with neonates, orienting in this situation appears limited to responding to present and past events.

The responses of the 4-month-olds were very different. The response between S1 and S2 indicated clear evidence of the early deceleration

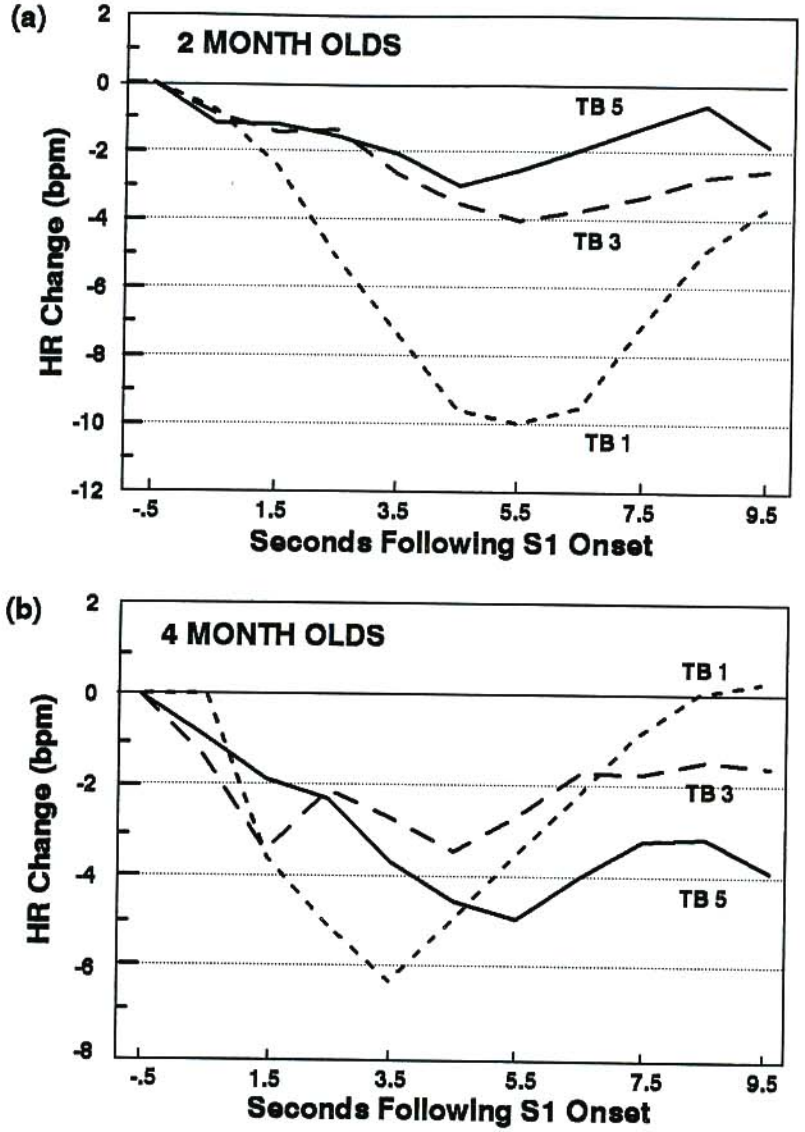

FIG. 15.4. Comparison of 2 and 4 month infant heart rate over the S1–S2 interval for TB 1–5. Only infants whose movements were below the median on TB 5 are included.

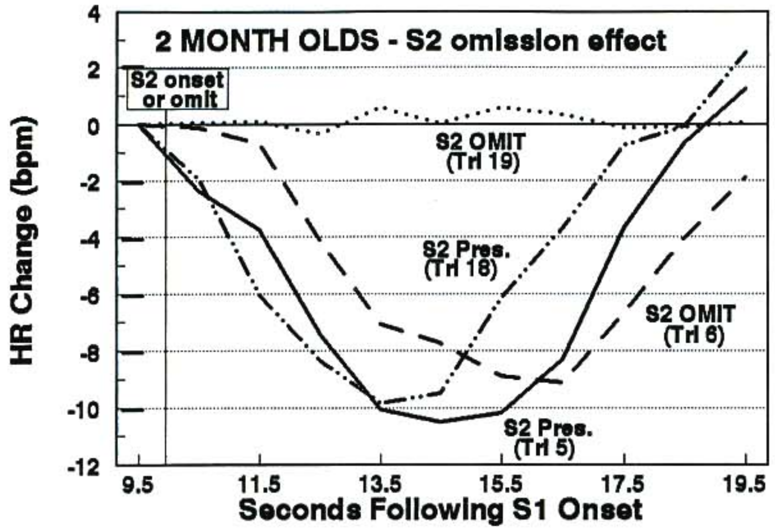

FIG. 15.5. Comparison of 2 month infant heart rate in response to omission of S2 onset (Trials 6 and 19) with HR response to presentation of S2 (Trials 5 and 18). (TRL = trial; S2 Pres. = S2 presented; S2 OMIT = S2 omitted).

habituating at the same time that the late deceleration was growing (Fig. 15.4b). The late deceleration increased almost monotonically over the five trial blocks. There was evidence of an omission response, though not as dramatic as the 2-month-old's omission response.

The 8-month-olds' response to S1 was complex and makes their data difficult to interpret. However, their responses were consistent with the results of three previous studies of this age group that demonstrated development of an anticipatory deceleration (Donohue & Berg, 1990, 1991; Donohue et al., 1992). We have found that this response is easily disrupted in 4- as well as 8-month-olds. The anticipatory responses appear to be limited to subjects who limit their movements during the stimulus period. The complex process of anticipation in the young infant may require maximal attentiveness in addition to motoric quieting.

The shift from Clifton's "What happened?" to the "Here it comes!" during the period between 2 and 4 months of life has important implications for our concepts of information processing. This review has focused on the cardiac responses of human infants, but other evidence suggests that these changes are not restricted to the autonomic nervous system. Haith and colleagues find anticipatory responding in visual fixation (rather than cardiac responses) for a variety of stimulus sequences in infants at 3 months of age (e.g., Haith et al., 1988; Lanthier, Arehart, & Haith, 1993). They report greater difficulties demonstrating this anticipatory response with 2-month-olds (Canfield & Haith, 1991). Our laboratory is currently working on additional measures of anticipation in infants including brain activity, reflex modulation, and overt behaviors. Research also shows that the development of anticipatory cardiac changes is also present in nonhuman species. Block and Montoya (1981) reported that 3-week-old kittens also fail to show classical conditioning of heart rate responses, but develop anticipatory responses by 8 weeks of age. These data suggest that the developmental change seen in anticipatory heart rate in human infants represents emergence of a basic cognitive activity during the first 4 months of life. The fact that the ability to anticipate develops sooner than what Piaget (1951, 1952) predicted is probably related to the use of measures more effective in testing very young infants and the careful attention to arousal state.

An important distinction must be made between responses occurring after an S2 event ("What happened?") and responses occurring before an S2 event ("Here it comes!"). The cognitive literature commonly assumes these responses are equivalent. For example, when following a series of similar stimuli the subject receives, without warning, a changed stimulus, the typical result is an enhanced or altered response (e.g., longer visual fixation or reaction time, or presence of a P300 component in an event related brain potential). As a class changes in these poststimulus responses are often referred to as "expectancy effects." The problem is that such terms may imply that an explicit anticipation for a particular stimulus was actively underway prior to the presentation of that stimulus. As a result, it is sometimes assumed that poststimulus and prestimulus responses are equally valid indicators of the cognitive construct of anticipation. The developmental evidence that post-S2 omission responses are present earlier than pre-S2 anticipatory responses indicates that such responses are independent processes, and thus pre- and post-S2 responses are not equally valid indicators of active, pre-S2 anticipation.

Given this, however, we are forced to provide an alternative explanation of just how an unexpected change in a previously predictable stimulus might alter a response to the changed stimulus. Sokolov's (1963) view of the neuronal model and orienting provides a reasonable answer. Sokolov proposed a neuronal comparator that takes information available from each stimulus as it is sensed and attempts to match it to the various stored "models" of previously experienced stimuli. If the new stimulus fails to match any existing model, then an orienting response is generated. But this process is not initiated until the new stimulus arrives. It does not presume nor require presence of active anticipation or prior orienting to the future event to account for this poststimulus response alteration. In this view, many of the so-called expectancy effects may rather be an indication that a mismatch to a previously stored stimulus model has

occurred. Thus, the newborn infant showing a large deceleration to the omission of a learned sequence may be simply orienting to this sequence that does not match an existing model of sequences.

In contrast, the process of anticipation requires some active attentional activity that is directed toward a forewarned, upcoming event. The principal evidence thus far that such attention is directed toward an upcoming event is that the index of attention, such as heart rate deceleration, develops over trials of paired stimuli and is usually maximal just prior to the S2. Haith's work on infants' visual saccades provides evidence that the ocular muscles activated prior to the upcoming event are ones that move the eye toward the next source of visual information. The neonate may have limited orienting and neuronal comparator capability, but does not appear to have the qualitatively distinct capability to attend to future events. It is not until later that true anticipatory responding occurs.

An important question not yet addressed is how the anticipation process relates to sustained attention. The literature on sustained attention and on anticipation allows us to pose some interesting research questions. For example, does the anticipatory response develop from the sustained deceleration? That is, is the anticipatory deceleration a refinement of sustained attention when paired stimuli are presented? If so, does anticipation reflect both the selective and intensive aspects found in sustained attention? Of course, anticipation may not originate from sustained attention. Sokolov argues that conditioning can take place (signal orienting, in his terms) only when the orienting response (and presumably any sustained attention) to the CS has habituated. Putnam, Ross, and Graham (1974) reported such effects for heart rate and the conditioned blink. This would suggest that sustained attention to the S1 (or CS) is explicitly incompatible with an anticipatory response. These and related questions can and should be answered by combining the procedures outlined by Richards for identifying sustained attention, with the S1–S2 paradigm being explored by Berg and others.

SUMMARY AND CONCLUSION

In this review we have argued that presentation of a stimulus initiates a series of attentive responses that differ in function and cognitive involvement. The validity of making qualitative distinctions between them is reinforced by the developmental changes that occur in these responses. During the first half year of life, the infant is building on the basic information processes available at birth. Simple preattentive processing is present and fully functional at birth. Orienting, which supplies basic information about the stimulus, is possible at birth but not very effective for the first 6 to 8 weeks. Following thereafter are the processes that allow continued examination and exploration of the stimulus at hand and the ability to prepare for, in at least a simple way, other stimuli which may be predicted from that which is at hand. Together these allow the infant in the second half year of life to focus narrowly and intensively both on that which is present now and that which may be possible in the future. These are powerful information processing tools needed to begin to organize the complex world the young infant faces.

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16

Attention, Emotion, and Reactivity in Infancy and Early Childhood

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Explorations into the orienting of attention continue to enhance our understanding of the development of sensory, perceptual, and cognitive abilities during infancy and early childhood. Although attention is often described in the cognitive terms of information processing, the connections between attention and affective/motivational processes are obvious in descriptive and theoretical accounts of early development (Berg & Sternberg, 1985; Izard & Malatesta, 1987; Piaget, 1981). Discussions of the complex relations between attention and affect are apt to proceed more quickly if we focus on the presumed phenomena rather than the words. Cognitive scientists are coming to a consensus that the abstract term *attention* involves, at a minimum, three quite different processes whose referents are (a) initial orienting following a change in the sensory field, (b) detection/selection of the event that was the source of the orienting—a more psychological phenomenon, and, finally, (c) sustained attentiveness to the event (Posner, 1995). It is reasonable to suggest that the successive and relatively seamless sequence that begins with orienting and ends with sustained attention is associated with excitability in different limbic-cortical systems (Posner, Rothbart, Gerardi, & Thomas-Thrapp, chapter 14, this volume; Robbins & Everitt, 1995; Stormack, Hugdahl, & Posner, 1994) and, therefore, with different emotions. This suggestion of connections between attention and emotion is supported, at a descriptive level, by infants' behaviors. Consider the following examples from our laboratories.