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Age Differences in Responses to Temporally Modulated Patterns at 6 and 12 Weeks

MARIE T. BALABAN
Harvard University

JAMES L. DANNEMILLER
University of Wisconsin–Madison

In this study of young infants' attentive responses to patterned visual stimuli, 6- and 12-week-old groups of infants responded differently, based on behavioral and cardiac indices of attention, to temporal modulation. Looking behavior and phasic heart-rate changes were measured while infants viewed checkerboard and bull's-eye patterns presented continuously, flashed at 1 Hz, or flashed at 5 Hz. For 12-week-old subjects, visual fixation increased with increasing flashing rate, and cardiac responses were more decelerative to flashing than to continuous patterns. For 6-week-old subjects, total durations of visual fixation did not differ among conditions; however, durations of first fixation to each pattern were reduced in the flashing conditions. These infants showed slight decelerative cardiac responses to the continuous and 1-Hz patterns but markedly accelerative responses to the 5-Hz patterns. State changes and/or movement increases were coded from videotape and were rejected as major contributors to this accelerative response. The observed differences between 6- and 12-week-old infants add to a multitude of evidence suggestive of discontinuities around 2 months of age.

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Correspondence and requests for reprints should be sent to Marie T. Balaban, Department of Psychology, Harvard University, William James Hall, 33 Kirkland Street, Cambridge, MA 02138.

Early in infancy, pulsed auditory stimuli typically elicit greater cardiac deceleration than do the same stimuli presented continuously (W.K. Berg & K.M. Berg, 1987; Bohlin, Lindhagen, & Hagekull, 1981; Rewey, 1973). This phasic slowing of cardiac rate, one index of the orienting response, has been interpreted as signifying attention to incoming stimulation (Graham, 1979; Graham & Clifton, 1966; Lacey & Lacey, 1974). Clarkson and W. K. Berg (1983) commented that "for both newborns and 6-week-olds, the temporal pattern of acoustic stimuli proves a crucial parameter controlling the cardiac component of the orienting response" (p. 169). The importance of stimulus onset, or change, in directing attention has been demonstrated by adult subjects in tasks where abrupt onsets of visual stimuli in the periphery temporarily capture attention from a primary display (Jonides & Yantis, 1988). Graham, Strock, and Zeigler (1981) suggested that young infants' processing of transient aspects of stimulation is quiet poor, thus pulsed stimulation may be especially effective in early infancy because the summation of multiple onsets and offsets more adequately stimulates the immature nervous system.

There is some evidence that the superiority of a temporally modulated stimulus in attracting infant attention also applies to the visual modality. Bushnell (1979) found that moving or flashing an internal element surrounded by an external contour increased attention to the internal form and disrupted the "externality effect" typically seen in infants younger than 2 months of age (Milewski, 1976). In a parametric comparison of the effects of flashing rate, from 1 to 20 Hz, on infant visual attention and electroencephalographic visual evoked responses, 13-week-old infants demonstrated visual preferences and maximal evoked-response amplitudes to stimuli flashing at about 5 to 6 Hz (Karmel, Lester, McCarvill, Brown, & Hofmann, 1977). Karmel et al. speculated that behavioral preferences may shift toward faster flashing rates with increasing age during infancy. Freedland and Dannemiller (1987) found that preferences of 20-week-old infants for oscillating, compared to static, random checkerboards varied as a function of temporal frequency, with maximal preference evidenced at 8 Hz.

Slow temporal modulation rates (e.g., 0.3–1 Hz) tested in the Bushnell (1979) visual study and in the auditory orienting studies, elicited increased attention to pulsed versus continuous stimulation in 1- to 3-month-old infants. Although there are marked stimulus and methodological differences among these studies and the studies of visual responses described before, an interaction of temporal rate and age parsimoniously accounts for the observed preferences and attentional effects.

In a study of visual evoked responses to alternating checkerboard stimuli, Moskowitz and Sokol (1980) found, similar to Karmel et al. (1977), a peak response at 4 to 5 Hz in 11- to 14-week-old infants. However, the peak response occurred at 2 Hz in 7- to 10-week-old infants. Thus, there appears to be support on a sensory level for the proposition that the optimal rate of temporal modulation changes with age in early infancy. It should be noted that optimal temporal rate probably interacts with the spatial characteristics of visual patterns; however, this aspect of visual development has not been studied in young infants (Moskowitz & Sokol, 1980; H.R. Wilson, 1988).

The age period from 6 to 12 weeks encompasses a period of rapid transition in visual development (Atkinson, 1984; Banks, Stephens, & Hartmann, 1985; Bronson, 1974). This period has also been characterized as a time of marked discontinuity for a variety of behaviors, including sleep and state organization, smiling behaviors, and reflex activities (Emde & Robinson, 1976; Papousek & Papousek, 1984; Prechtl & Hopkins, 1986). Described transitions include not only the disappearance of some neonatal behaviors, but the temporary suppression of certain abilities that later reemerge (e.g., Field, Muir, Pilon, Sinclair, & Dodwell, 1980).

Changes in the cardiac orienting response are also apparent at these early ages. Although infants from 3 to 7 months of age show exaggerated cardiac decelerative responses to a wide range of stimuli, younger infants' decelerative responses occur to a more restricted set of stimulus conditions. The failure of many early studies to demonstrate deceleratory orienting responses can be attributed to fluctuations in infants' state. However, later studies, in which state was carefully assessed, continued to find that deceleratory responses were more elusive in infants younger than 3 months of age (Adkinson & W.K. Berg, 1976; W.K. Berg & K.M. Berg, 1987; Graham, Anthony, & Zeigler, 1983). In a recent study of 8-week-olds' cardiac responses to various visual patterns, Richards (1989) found that orienting to stimulus onset was reduced compared to responses typical of older infants and that peak deceleration for 8- and 14-week-old infants was also reduced compared to older infants.

Both visual fixation behaviors and cardiac responses have been used as measures of infant visual attention. Based on fixation behaviors, infant visual attention has been divided into separable component processes: (1) attention getting, or the initial recruiting of attention, and (2) attention holding, or the sustaining of interest in the stimulus (Cohen & Gelber, 1975). In this model, temporal modulation would presumably increase at least the attention-getting properties of a stimulus. An analogous theoretical distinction has been proposed to explain infant cardiac responding, that is, phasic heart-rate deceleration is sensitive to the initial orienting of attention to the stimulus, whereas the duration of the cardiac response reflects sustained attention to the stimulus (Richards, 1988; R.S. Wilson, 1980).

In an attempt to assess empirically whether these component attentional processes similarly influence infants' physiology and behavior, Finlay and Ivinskis (1982) measured both the cardiac response and visual behavior of 15-week-old infants. Slowly or rapidly moving stimuli were presented for either a short 2-s duration, designed to elicit predominantly attention-getting processes, or a longer 9-s duration, designed to elicit both attention getting and attention holding. Visual fixation was not affected by speed of movement; however, this lack of difference could have been due to a ceiling effect because latency to fixation was very short, and fixation duration approached the total stimulus duration. The cardiac response to the moving stimuli, although somewhat obscured by the use of a warning signal which itself initiated cardiac deceleration, was more decelerative to the fast than to the slow stimuli presented for the short duration, as would be expected if rapid movement enhanced attention getting.

Attention to different temporal rates of visual stimulation, as indexed by behavioral preferences and/or cardiac responsiveness, has not been systematically investigated across age in early infancy. In the current experiment, our purpose was to examine the influence of temporal modulation on infant visual attention. Two age groups, 6 weeks and 12 weeks, were included in order to span the developmental transitions previously noted. The hypotheses were that temporal modulation would facilitate infant attention and that this effect might interact with age, such that the older infants preferred faster temporal rates than the younger infants. In addition to a control condition where patterns were presented continuously, we tested two rates of temporal modulation, 1 Hz and 5 Hz, in order to allow comparison with results of previous research. Patterns were temporally modulated by flicker rather than by motion, because differences in motion detection thresholds have been found at these ages (Aslin & Shea, 1990; Dannemiller & Freedland, 1991). Both cardiac responses and visual fixation were measured to assess visual attention, and a secondary question of interest was whether these behavioral and physiological dependent measures would be correlated early in infancy.

METHOD

Subjects

Subjects were recruited from published birth announcements in the Madison, Wisconsin area. The final sample included 48 infants: 12 males and 12 females at approximately 6 weeks of age (35–51 days) and 13 males and 11 females at approximately 12 weeks of age (79–94 days). The 12-week group included one set of male twins. Additional infants were tested but not included for the following reasons: experiment terminated prior to completing half the trials due to infant's drowsy or fussy state (6 weeks, n = 10; 12 weeks, n = 11), experiment completed but insufficient number of trials to meet state and looking-time criteria described in procedure (6 weeks, n = 3; 12 weeks, n = 7), inadequate heart-rate recording (6 weeks, n = 1; 12 weeks, n = 2). All accepted subjects were born within 2.5 weeks of term and were free of any major health problems. Median level of parental education, self-reported on a questionnaire, was 16 year for both parents.

Apparatus

Infants were tested while seated in an infant seat in an acoustically shielded chamber. Visual stimuli, controlled by an Apple II computer, were presented on a color monitor about 45 cm in front of the infant. The patterns were dark and light green checkerboards and bull's-eyes, presented at 70% contrast, with luminance of the dark and bright elements at 8.5 cd/m^2 and 35.7 cd/m^2, respectively. The 8 × 8 checkerboard subtended a visual angle of 26°, with individual checks of 3.25°. The bull's-eye pattern, with three dark and two light rings, subtended a visual angle of 27°, with element width of 3°. The large element size was selected so that patterns presumably would be visible to infants at the ages tested (Banks & Ginsburg, 1985; Karmel & Maisel, 1975). In the flashing conditions, the screen display alternated, with a 50% duty cycle, between the pattern and a uniform green field equal in luminance the dark pattern elements.

The electrocardiogram was recorded from three standard Ag/AgCl electrodes (Sensormedics), filled with Liqui-Cor cream and taped to the infant's chest. The signal was led through a Hewlett-Packard model 78213C neonatal monitor, digitized at 280 Hz, and stored on a second Apple II computer for off-line analysis.

Design

Twelve 16-s trials were separated by intertrial intervals between 13 and 15 s. Each pattern, checkerboard (C) and bull's-eye (B), was presented twice at each flashing rate: continuous, 1 Hz, and 5 Hz. The patterns were blocked in a BCCB or CBBC design, with each block including one trial of each temporal rate. The order of flashing conditions was held constant within a subject but varied across subjects, thus the six possible combinations of flashing conditions and the two pattern orders yielded 12 trial orders. For example, a given subject would view checkerboards at 5 Hz, continuous, and at 1 Hz, respectively, for Trials 1 to 3 and Trials 10 to 12, and view bull's-eyes at 5 Hz, continuous, and at 1 Hz for Trials 4 to 6 and Trials 7 to 9. Two subjects from each age group were randomly assigned to each trial order.

Procedure

Upon arrival at the laboratory, the experiment was described to the parents, their consent was obtained, and the recording electrodes were placed on the infant's chest. After a 3-min baseline period, the infant was placed in the infant chair for the experimental trials and parents were seated behind their infants. The room lights were turned off and, after about 30 s for adaptation to the blank screen, the 12 stimulus trials were presented. An observer, seated behind the screen and out of the infant's view, coded the infant's fixation behavior on-line by looking through a small opening in the frame surrounding the screen. The observer, using a button press, coded infant fixation whenever the stimulus was reflected off the infant's cornea, over the area of the pupil. If necessary, the observer postponed onset of a trial until the infant returned to an alert state. Visual fixation was digitized on-line by the Apple II computer, which also sampled the cardiac signal from 2 s preceding through 2 s following each trial. Experimental sessions were videotaped for off-line rating of infant state.

Subjects included in the study were required to have at least 1 acceptable trial for each of the six combinations of pattern and flashing rate. Trials were rejected based on state and looking criteria described later, and for experimenter or parent interference (2% of total trials). Subjects completed an average of 11.6 of the 12 total trials, and the mean number of acceptable trials was 9.7 for the 6-week-olds and 10.4 for the 12-week-olds.

Data Analysis

Visual Fixation. Two measures of visual fixation were obtained: (1) total fixation duration, that is, the cumulated seconds of looking for each trial; and (2) duration of first fixation, that is, duration of the infant's initial look toward the stimulus on each trial. For the latter measure, transient looks away from the stimulus (< 0.25 s) were ignored. Trials with total fixation durations of <1 s (4% of total trials) were excluded from all analyses.

Cardiac Responses. The cardiac signal was digitally filtered with an 8-point moving rectangular function to remove low frequencies and enable easier computer scoring of R-wave peaks. The R–R intervals were scored, edited if necessary, and converted to heart rate in beats per minute (bpm) for each second from 1 s preceding through 1 s following stimulus presentation. For this conversion, the number of full and fractional beats was multiplied by 60 to yield bpm values (Graham, 1978). Two dependent measures of heart rate were analyzed: *Mean heart-rate change*, to assess effects over the entire trial and to provide a variable for correlations with fixation-duration measures, and *per second heart rate*, to describe the form of the heart-rate change during the trials and for statistical trend analysis. A mean heart-rate-change score was calculated for each trial by subtracting each per-second heart-rate value during the 16-s stimulus from the prestimulus heart-rate value, and averaging the resulting change scores. Analyses of polynomial trends utilized the 16 1-s epochs of heart rate, anchored to the prestimulus beat. For the repeated variable of seconds in these analyses, degrees of freedom for specifying critical F values were adjusted using the maximal Geisser-Greenhouse correction values (Keppel, 1982).

State and Movement Ratings. State was rated off-line from videotape as alert, fussy, crying, or drowsy, according to behavioral criteria adapted from K.M. Berg, W.K. Berg, and Graham (1971). Four consecutive 5-s epochs were rated for each trial, beginning about 3 s prior to stimulus onset. Trials were accepted only if the first epoch and two of the remaining three epochs were rated as alert. Approximately 7% of the total trials were rejected due to state. A second observer, naive to the experimental hypotheses, coded state for 20% of accepted subjects. The agreement for the two observers ranged from 83 to 100% over all epochs. For post-hoc analysis of movement, cardiac-somatic coupling, and state, a third observer, also naive to the experiment's purpose, coded from videotape the arm and head movements of the infants during stimulus trials according to a rating scale adapted from Emde, Campos, Reich, and Gaensbauer (1978). A value of 0, 1, or 2 was assigned to each arm and to the head, yielding a maximum movement score of 6 points. The average movement score across the four 5-s epochs on each trial was obtained. For reliability of movement ratings between the experimenter and the third observer, assessed for 10% of the subjects, agreement was defined as summed movement scores within 1 point for an epoch; such agreements comprised 95% of all ratings. The observer also reported a forced-choice response on every trial regarding whether or not any facial sign of fussiness was displayed at any time during the trial.

RESULTS

Visual Fixation

Inspection of the *total* fixation durations for each flashing condition at each age, shown in Figure 1 (p. 366), indicates that 12-week-olds showed a monotonic increase in looking time with increasing flashing rate, but 6-week-olds showed no apparent differences. This result was confirmed in a $2 \times 2 \times 3$ (age $\times$ pattern $\times$ rate) ANOVA, with the age $\times$ rate interaction, $F(2, 92) = 4.65$, $p < .025$. Separate age analyses showed no significant differences among rate conditions for 6-week-olds but a significant main effect of rate for 12-week-olds, $F(2, 46) = 6.78$, $p < .01$.

Analysis of the duration of *first* fixation, also illustrated in Figure 1, showed a similar age $\times$ rate interaction, $F(1, 92) = 4.56$, $p < .025$, with an age difference in the linear trend across rate conditions, $F(1, 92) = 9.11$, $p < .01$. The 12-week-old infants showed a significant increase in initial look duration with increasing rate, whereas the 6-week-olds showed a nonsignificant decrease, $Fs(1, 46) = 6.92$ and 2.99, $p < .025$ and $p < .10$, respectively.

A pattern $\times$ rate interaction was significant for both first and total fixation duration analyses, $Fs(2, 92) = 3.93$ and 3.16, $p < .05$. Total fixation of checkerboards was about 0.7 s longer than fixation of bull's-eye patterns in the continuous and 1-Hz conditions and total fixation of bull's-eye patterns about 0.6 s longer than fixation of checkerboards in the 5-Hz condition, but this effect did not interact with age.

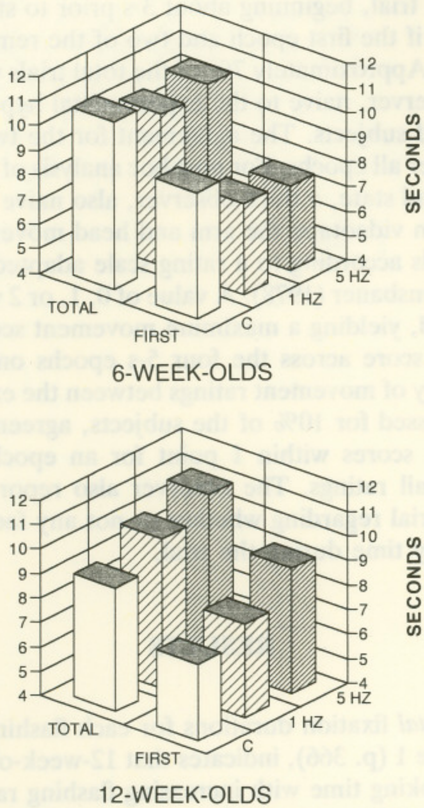

Figure 1. Means of total fixation duration and the duration of first fixation for each flashing condition, C (continuous), 1 Hz, and 5 Hz, for 6- and 12-week-old infants. For 6-week-olds, standard errors for C, 1-Hz, and 5-Hz conditions were 0.96, 0.76, 0.74 s for first and 0.74, 0.57, 0.57 s for total fixation. For 12-week-olds, corresponding values were 0.77, 0.71, 0.73 and 0.55, 0.53, 0.52.

Cardiac Responses

The age difference in heart rate during the *prestimulus* second was significant, $t(46) = 2.73$, $p < .01$, with higher heart rates for 6- than for 12-week-olds (155 bpm vs. 148 bpm). Within each age group, analyses of prestimulus heart rate for each flashing condition compared to the continuous condition showed no significant differences, $ts(46) < 1$. For this reason, and because trend analyses are typically unaffected by prestimulus level (K.M. Berg et al., 1971; Graham & Jackson, 1970), change scores were analyzed without adjustment for prestimulus level.

Analyses of *mean heart-rate change* across the 16 s of pattern presentation, tested with a 2 × 3 × 2 (age × rate × pattern) ANOVA, indicated a main effect of temporal rate and an interaction of rate with age, $Fs(2, 92) = 3.25$

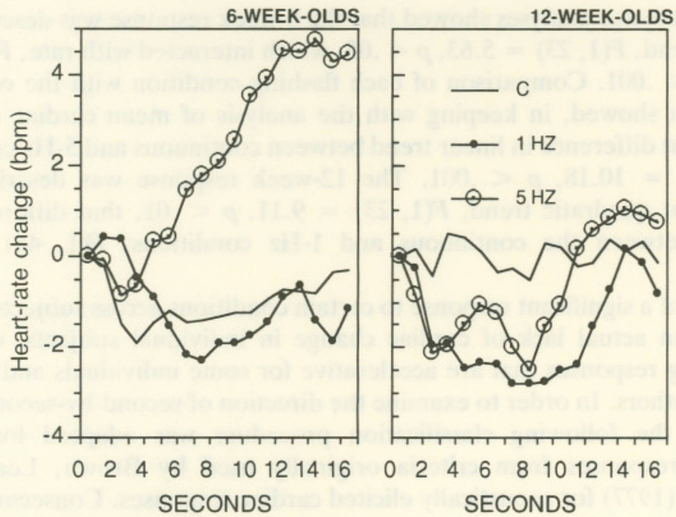

Figure 2. Second-by-second evoked heart-rate changes from the prestimulus second for each flashing condition.

and 3.26, respectively, $p < .05$. The mean cardiac responses of the 12-week-olds were in the decelerative direction in the flashing conditions, but no average response was apparent in the continuous condition. The 6-week-olds, however, showed mean heart-rate changes in the decelerative direction to the continuous and 1-Hz patterns, but a marked acceleratory mean change to the 5-Hz patterns. Within-age comparisons of each flashing condition to the continuous condition showed that the accelerative difference between continuous and 5-Hz conditions was significant at 6 weeks, and the decelerative difference between continuous and 1-Hz conditions was significant at 12 weeks, $Fs(1, 46) = 5.60$ and 4.40, respectively, $p < .05$.

The form of the average cardiac response is displayed as second-by-second heart-rate difference curves in Figure 2. The *per second heart rate* data were initially analyzed in a $2 \times 2 \times 3 \times 16$ (age $\times$ pattern $\times$ rate $\times$ seconds) ANOVA in polynomial trends. As with the analysis described before, no effects of pattern were significant, therefore, the results of trend analyses collapsed over pattern are described here. The cardiac response showed a significant main effect of seconds, $F(1, 736) = 6.26$, $(df_{\text{adj}} = 1, 46)$, $p < .025$, and significant linear, quadratic, and cubic trends, $F(1, 46) = 7.34$, $p < .01$, $F(1, 46) = 12.54$, $p < .001$, and $F(1, 46) = 4.91$, $p < .05$, respectively. The flashing rate $\times$ seconds interaction and the flashing-rate interaction with the linear trend were significant, $F(32, 1472) = 4.14$, $(df_{\text{adj}} = 1, 46)$, $p < .05$, and $F(2, 92) = 9.76$, $p < .001$. For the age $\times$ rate $\times$ seconds interaction, the linear trend approached significance, $F(2, 92) = 3.05$, $p = .052$.

Separate age analyses showed that the 6-week response was described by a linear trend, $F(1, 23) = 5.63$, $p < .05$, which interacted with rate, $F(2, 46) = 9.59$, $p < .001$. Comparison of each flashing condition with the continuous condition showed, in keeping with the analysis of mean cardiac change, a significant difference in linear trend between continuous and 5-Hz conditions, $F(1, 46) = 10.18$, $p < .001$. The 12-week response was described by a significant quadratic trend, $F(1, 23) = 9.11$, $p < .01$, that differed significantly between the continuous and 1-Hz conditions, $F(1, 46) = 5.51$, $p < .01$.

Lack of a significant response to certain conditions across subjects could be due to an actual lack of cardiac change in individual subjects, or due to averaging responses that are accelerative for some individuals and decelerative for others. In order to examine the direction of second-by-second cardiac change, the following classification procedure was adapted for visually elicited responses from criteria originally used by Brown, Leavitt, and Graham (1977) for acoustically elicited cardiac responses. Consecutive directional changes maintained over at least 5 of the first 12 s following stimulus onset with a peak magnitude of at least ± 4 bpm were classified as accelerative or decelerative. The outcome of this descriptive classification, which resulted in a directional response in 77% of all cases, is illustrated in Figure 3. Note that the number of subjects with decelerative responses decreased with flashing rate in the 6-week-old group and increased in the 12-week-old group; the converse generally held true for accelerative responses.

In an attempt to examine the initial response to stimulus onset, presumed to index primarily phasic attention-getting processes, an additional trend analysis included only the prestimulus and first 3 poststimulus seconds. Results indicated a significant linear trend, $F(1, 46) = 12.68$, $p < .001$, and an interaction of age and rate in the linear response, $F(2, 92) = 3.56$, $p < .05$.

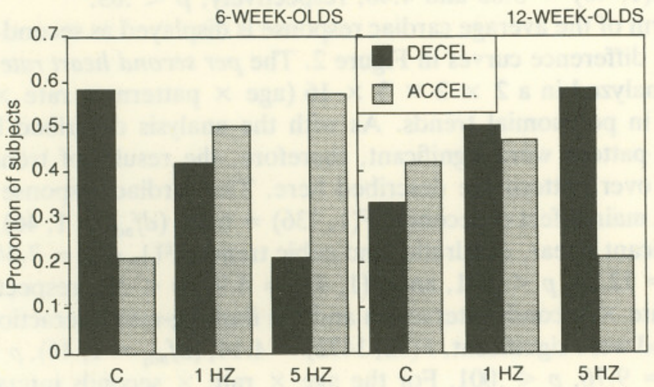

Figure 3. Directional classification of heart-rate responses as decelerative or accelerative for each flashing condition for 6- and 12-week-old infants.

For the 12-week-group, both the 1-Hz and the 5-Hz flashing conditions differed significantly in linear trend from the continuous condition, $Fs(1, 46) = 5.58$ and 4.41, respectively, $p < .05$. As seen in Figure 2, the temporally modulated patterns elicited steeper initial deceleration than did the continuous patterns. For the 6-week group, the significant linear trend, $F(1, 46) = 6.31$, $p < .025$, was also in the deceleratory direction, but did not differ among flashing conditions.

Correlations Between Cardiac and Looking Indices of Attention

In order to determine whether visual fixation and cardiac change were related, the mean heart-rate-change scores and total fixation durations were separately correlated for each age and flashing-rate condition. The resulting correlations were small and nonsignificant, with the exception of the correlation for the 6-week-old infants in the 5-Hz condition. The modest negative correlation, $r = -.40$, $p = .05$ (Pearson's r, two-tailed), indicated that longer visual fixations were associated with less accelerative cardiac responses.

Post-Hoc Movement and State Ratings

Scores for head and limb movements, tested in an age × rate ANOVA, averaged 1.5 on the 6-point rating scale and did not differ as a function of age or flashing condition. For the 6-week-old group, correlations by condition between mean cardiac change and movement scores were +.37, +.38, and +.19 for continuous, 1-Hz, and 5-Hz conditions, respectively. Corresponding values for the 12-week-old group were +.29, +.22, +.28. For the 6-week-old group, the percentage of trials for which any facial signs of fussiness were noted were 13%, 9%, and 17% for continuous, 1-Hz, and 5-Hz conditions. Corresponding values for the 12-week-old group were 14%, 5%, and 7%.

DISCUSSION

Results for the 12-week-old infants supported the hypothesis that temporally modulating a stimulus can enhance infants' attention: The flashing patterns elicited longer fixation durations and more decelerative cardiac responses than did the continuously presented patterns. These results complement previous findings of larger cardiac decelerations to pulsed than continuous sounds at 12 weeks (Bohlin et al., 1981). The small magnitude of the 12-week-olds' cardiac responses is probably due to the similarity of the stimuli and the number of trials. Richards (1989) reported larger decelerations to visual stimuli in 8-week-olds, but both the range of patterns and the types of temporal variation varied considerably in the stimulus set. The 12-week-olds in the Bohlin et al. experiment showed deceleration to pulsed sounds for all 10 of the familiarization trials; however, the response habituated markedly following the fourth trial. If pattern preferences could be equated a priori, further experiments of temporal rate could include a variety of different patterns to minimize habituation effects.

This experiment also showed consistent interactions of age with temporal modulation rate. Whereas flashing a stimulus increased measures of attention in 12-week-old infants, slowly flashing a stimulus did not increase attention and quickly flashing a stimulus may have decreased attention in 6-week-olds. The accelerative response of 6-week-old subjects to the 5-Hz patterns was robust and quite distinct from their average response to the other conditions. Several potential interpretations, not necessarily mutually exclusive, merit discussion. One possibility is that the observed acceleration was secondary to some other effect of the 5-Hz modulation, such as body movement or state changes.

The tendency for increased heart rate to be associated with increased body movement has been described as cardiosomatic coupling (Obrist, Webb, Sutterer, & Howard, 1970). The potential for such an influence on infants' cardiac responses is supported by the finding that newborns exhibited cardiac deceleration to laterally presented sounds only on trials when no head turning occurred (Morrongiello & Clifton, 1984). In the same study, 5-month-old infants showed cardiac deceleration despite head-turning activity, although the magnitude of deceleration was reduced on trials with, compared to without, head movements. Similarly, cardiosomatic coupling was noted for 1- but not 3-month-olds to rocking stimulation (Malcuit, Pomerleau, & Brosseau, 1988). The possibility that, in this experiment, body movement was a critical factor in producing the acceleratory cardiac change is unlikely, because the movement ratings coded by a naive observer did not differ among temporal rate conditions. Furthermore, the obtained correlations between mean cardiac change and movement scores indicated that cardiosomatic coupling appeared least evident in the 5-Hz conditions for the younger group.

Could changes in state, produced by rapid flashing of the patterns, be primarily responsible for the accelerative response? Brackbill (1970) found that pulsed sound increased 1-month-olds' heart rate, movement, and time spent in alert or crying states relative to continuous sound. Volkmann and Dobson (1976) measured visual preferences for moving stimuli at rates up to 2 Hz in groups of 1-, 2-, and 3-month-old infants. Their results showed strong preferences for moving stimuli, but they also noted that the behavior of the infants gave the impression that they disliked the most rapidly moving stimulus, that is, infants tended to look toward the stimulus and then avert their gaze. In this experiment, although trials with definitive state changes according to the set behavioral criteria were eliminated from analyses, it is possible that the 6-week-olds were more likely to show slight indications of agitation, such as facial signs of displeasure, in the 5-Hz than in the other conditions. However, the post-hoc analyses of occurrence of facial signs of fussiness showed only a slight increase in occurrence between the 5-Hz and the 1-Hz conditions, which seems inadequate to account for the large cardiac differences between these conditions.

A second category of explanation for cardiac acceleration to the 5-Hz stimuli is that the accelerative response is a concomitant of orienting at this age. The elusiveness of decelerative responses at 6 weeks was described previously, and the finding of accelerative responses is not without precedent at this age. For example, 6-week-old infants showed deceleratory responses to changes in tone frequency, but acceleratory responses to changes in pulsed vowel sounds (Leavitt, Brown, Morse, & Graham, 1976). The hypothesis that the morphology of the cardiac orienting response is accleratory at 6 weeks has been rejected by several investigators (W. K. Berg & K. M. Berg, 1987; Graham et al., 1983). In fact, this experiment also offers one argument against the interpretation of acceleratory change as orienting. The correlation between cardiac change and fixation duration for 6-week-olds in the 5-Hz condition was negative, so that subjects with more accelerative responses showed shorter fixation times, the opposite of what might be expected at this age if attention to the rapidly flickering patterns were enhanced.

A third interpretation of the accelerative response is that it signifies a process limiting the effects of stimulation or a lack of attention to ongoing stimulation (Graham, 1979; Lacey & Lacey, 1974). Richards (1987, 1988) found that older infants are more likely to be distracted by a secondary stimulus if their heart-rate response to a primary visual stimulus was accelerating at the time of interruption than if their heart rate was decelerating. This effect was similar, although not significant, in a study of 8-week-old infants (Richards, 1989). In this experiment, it is possible that the 6-week-olds' decelerative heart-rate change in the initial 3 s of the response represents a weak orienting or "transient-detecting response" (Graham, 1979). The delayed accelerative component in the 5-Hz condition could reflect stimulus rejection or lack of attention, even though the infants do not or cannot move their eyes from the pattern rapidly. The familiarization and/or novelty preference paradigm might be used to test further the hypothesis that cardiac acceleration reflects lack of attention. Infants who respond predominantly with cardiac acceleration during familiarization to a pattern would be expected to show less of a novelty preference than infants who respond with cardiac deceleration.

Is it possible that the younger infants could not distinguish the pattern information in the 5-Hz flashing display? Although neonates, tested in a calm state, prefer increasing rates of temporally modulated unpatterned light from 1 to 8 Hz (Gardner & Karmel, 1984), and the critical flicker frequency for uniform, unpatterned fields is 40 Hz or greater by 6 weeks (Regal, 1981), sensitivity to spatiotemporal information in flickering *patterns* could be immature. There is some evidence from studies of infant visual preferences and pattern visual evoked responses that temporal tuning in the visual system changes with age. The optimal range of temporal modulation shifts to higher rates with increasing age and also may interact with the spatial characteristics of the stimulus (Moskowitz & Sokol, 1980; Sokol, Moskowitz, McCormack, & Augliere, 1988). The patterns used in this experiment had large element sizes and should have been well within the resolution of 6-week-old infants, even when modulated at 5 Hz (Moskowitz & Sokol, 1980). Thus, it seems more likely that the differences between 6- and 12-week groups in this experiment reflect maturational changes in attentional rather than primary visual processes, although admittedly it is difficult to disentangle the source of the age-related change.

Distinctions between explanations based on sensory development and explanations involving other, potentially higher level, processes are most obvious when infant preferences violate predictions based on current knowledge of sensory development. Studies of infants' responses to facelike stimuli provide one such case. Although preferences of infants younger than 2 months were predictable based on stimulus characteristics and models of visual processing, preferences of older infants appeared biased toward face-like stimuli despite predictions based strictly on sensory development (Dannemiller & Stephens, 1988; Kleiner, 1987; Kleiner & Banks, 1987).

The dependent measures used in this experiment, cardiac change and visual fixation, are widely used as indices of attention. There is some concordance apparent between the two dependent measures for the 12-week-olds: Visual fixation increased with increasing temporal rate, and, although the cardiac response to the 5-Hz patterns was not larger than that to the 1-Hz patterns, cardiac deceleration was greater for flashing than for continuous conditions. The pattern of results for the 6-week-olds' cardiac responses and visual fixation is quite different, lacking any obvious association. Richards (1989) proposed that behavioral and physiological indices of visual attention are dissociated in early infancy and become more closely related at 14 to 26 weeks. It remains unclear whether this is due to the immaturity of processes controlling cardiac change and/or processes controlling visual scanning.

The present demonstration of marked developmental change between 6 and 12 weeks in cardiac and behavioral responses to temporally modulated visual stimulation is consistent with a multitude of studies suggesting that an important developmental transition occurs at about 2 months. Some of these changes include proposed differences in control of visual attention processes. Bronson (1990) reported the emergence, at 6 to 8 weeks, of various aspects of scanning behavior in infants. Braddick and Atkinson (1988) suggested "that the appearance of a pattern controls the direction of visual attention, as expressed in fixation behavior, in rather different ways in 1- and 2- to 3-month-olds." (p. 124). Further understanding of intensive and selective aspects of attentional control processes in adults and of the neural mechanisms underlying such processes (Posner, 1986; Posner, Walker, Friedrich, &

Rafal, 1984) may provide insight into the development of such attentional influences and mechanisms during the course of early infancy.

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