The Development of Sustained Visual Attention in Infants from 14 to 26 Weeks of Age

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ABSTRACT
The development of sustained visual attention was examined in infants cross-sectionally at 14, 20, and 26 weeks of age. Heart rate, heart rate variability, and respiratory sinus arrhythmia were measured in a 5-min baseline period. Two methods for measuring visual attention were used. The "infant control" method consisted of checkerboard presentations which were terminated when the infant looked away from them. The "interrupted stimulus" method consisted of a blinking panel in addition to the checkerboard patterns in order to attempt to actively terminate the fixation. The visual and cardiac responses during the interrupted stimulus method were more highly correlated with baseline respiratory sinus arrhythmia than were the responses during the infant control trials. The long latency heart rate responses during the interrupted stimulus trials showed a developmental change toward more mature response patterns from 14 to 26 weeks of age. It may be concluded that: 1) sustained attention, measured with the interrupted stimulus method, increases from 14 to 26 weeks of age; and 2) baseline respiratory sinus arrhythmia is correlated with sustained attention responses and their development.

DESCRIPTORS: Infancy, Heart rate, Respiratory sinus arrhythmia, Visual attention, Sustained attention.
from hypothetic developmental changes in pattern preferences (Karnell & Mainel, 1975), and corresponded to the approximate maximum preferences for contour density at 8, 14, and 20 weeks of age. The interrater reliability of infant attention during the interrupted stimulus task was defined as the power of the heart rate spectrum at the modal frequency. Therefore, the interrupted stimulus task measured infant attention to the physiological measures were extracted separately from the data for the factorial design for the analysis of the results. These measures were computed from heart rate mean and variance at 0.5-s intervals, and the respiratory frequency for the quantification of respiratory sinus arrhythmia. Infant heart rate-related period (20 ms resolution) was measured with a cloth belt placed around the infant's chest, and a mercury stage count was used to detect instantaneous heart rate changes. The respiration signal was digitized online at 50 Hz by an Apple IIc computer. Respiration frequency was quantified only for the baseline period, since the infant was chosen to coordinate the computation of mean heart rate with the computation of mean fixation duration in the attention trials (Graham, 1978; Richards, 1980).

Heart rate variability measures were quantified from the baseline period recorded the mean and variance of the 0.5-s intervals of the baseline were computed for heart rate. The variance of the heart rate intervals was computed by the mean absolute value of the first derivative of the data analysis. Two measures were computed for the baseline period based on spectral analysis procedures. These measures were computed from heart rate measures assigned to 0.5-s intervals, and the respiration signal sampled at 0.1-s intervals. The first 512 0.1-s intervals of each of the 5 min was used, giving a free-breathing period of 0.05 s per infant. The spectral analysis measures were extracted separately from the data for each baseline minute, and the extracted measures were averaged over these 5 baseline periods. The extent of sinus arrhythmia was defined as the power of the heart rate spectrum at the modal respiration frequency for that baseline period (Harper et al., 1978; Porges et al., 1982). This power measure was transformed by the natural logarithm function for the data analysis. The weighted coherence was defined as the proportion of variance of the heart rate spectrum that was predictable from the coherence between heart rate and respiration (Porges et al., 1980). Infants were presented with primary visual stimuli which were interrupted by a secondary visual stimulus on one-half of the trials. Checkerboard patterns of differing complexity were used as the primary stimulus in order to obtain varying amounts of attention. Heart rate responses were calculated during the presentation of the central stimulus and attention to the central task was defined as the amount of time that the infant fixated on the stimulus. The amount of cognitive resources dedicated to the task by the subject is "subject-controlled," endogenous attention, and therefore is the "sustained attention" defined by Porges (1976, 1980).

Therefore, baseline heart rate variability (e.g., respiratory sinus arrhythmia) should be more highly correlated with the interrupted stimulus trials, since the former occurred during the interrupted stimulus trials than during the control trials, since the former procedure is a better measure of sustained visual attention.

Methods

Subjects

Infants for this study were recruited from birth notices in a Columbia, South Carolina, newspaper. The infants were full-term, and the parents reported no pre- or perinatal medical complications. A cross-sectional design was used to sample infants at 14, 20, and 26 weeks of age. The mean testing age of the infants was 198.8 days (SD = 2.68), 182.6 days (SD = 2.25), and 182.2 days (SD = 1.80), respectively. Eighteen subjects at each age were used. In order to optimize cardiovascular and visual responding, the testing was done only if the subjects maintained an alert, awake state during the entire procedure (eyes open, no fussing or crying, responding to the protocol). Nine additional infants did not complete the testing because they did not maintain this state.

Apparatus

The infant was held in his parents' lap approximately 51 cm from the center of a black and white 49 cm (19 in.) television monitor. There was a single LED located on either side of the television screen 23 cm from the center, and one located on the bottom center. These LEDs blinked at a rate of 3.33 Hz when turned on. A video camera lens was located above the television monitor, and a television monitor was located in an adjacent room and was used by an observer to record infant fixations. The area around the television monitor and arrows, and the sides of the perinatal monitor, was covered with a neutral-colored cloth panel in order to block extraneous visual information. The stimuli for the central task (primary stimuli) were presented continuously. The infants were presented on the television monitor in a 30 cm (1 ft) square area and were either 2.54, 12.7, or 0.635 cm (0.0, 0.5, or 0.25 in.) in size. The patterns were either presented continuously or changed from black to white at 6.25 Hz. The sizes of the checks were chosen with an Apple IIe microcomputer by identifying the R-R intervals in the EKG with 1 ms resolution. The beat-to-beat heart period intervals were converted to heart rate (bpm) by assigning values to equal intervals determined by the proportion of time that the beat occupied the interval. Heart rate was calculated on a 0.5-s by 0.5-s interval and measured in bpm by 0.1-s basis for the spectral analysis measures. Respiration was measured with a cloth belt placed around the infant's chest, and a mercury stage count was used to detect instantaneous heart rate changes. The respiration signal was digitized online at 50 Hz by an Apple IIc computer. Respiration frequency was quantified only for the baseline period, since the infant was chosen to coordinate the computation of mean heart rate with the computation of mean fixation duration in the attention trials (Graham, 1978; Richards, 1980).

Heart rate variability measures were quantified from the baseline period recorded the mean and variance of the 0.5-s intervals of the baseline were computed for heart rate. The variance of the heart rate intervals was computed by the mean absolute value of the first derivative of the data analysis. Two measures were computed for the baseline period based on spectral analysis procedures. These measures were computed from heart rate measures assigned to 0.5-s intervals, and the respiration signal sampled at 0.1-s intervals. The first 512 0.1-s intervals of each of the 5 min was used, giving a free-breathing period of 0.05 s per infant. The spectral analysis measures were extracted separately from the data for each baseline minute, and the extracted measures were averaged over these 5 baseline periods. The extent of sinus arrhythmia was defined as the power of the heart rate spectrum at the modal respiration frequency for that baseline period (Harper et al., 1978; Porges et al., 1982). This power measure was transformed by the natural logarithm function for the data analysis. The weighted coherence was defined as the proportion of variance of the heart rate spectrum that was predictable from the respiration spectrum (Porges et al., 1980), and was summed over 0.1953 Hz (11.71 breaths per min) centered at the modal respiration frequency for the period.

Experimental Design for Statistical Analysis

The factorial design for the analysis of the results included testing age as a between-subjects factor, and within-subjects factors for infant control and interrupted stimulus trials, blinking checks (blinking and non-blinking checks), and checkerboard presentation. The across-subjects factor was the order of the dependent variables on the two control trials
were subtracted from the levels on the experimental trials. There was no "intervals" factor for the 0.5-s by 0.5-s heart rate data, since the trials were necessarily of differing lengths. The relationship between baseline heart rate variability and attention responses was assessed by correlations between the baseline measures and the attentional responses. Unless noted, the significance of the ANOVA test was unchanged by applying the maximum conservative adjustment of the degrees of freedom according to the Greenhouse and Geisser method (see late, 1959; see as Richards, 1980). However, if the maximum conservative adjustment resulted in a nonsignificant ANOVA, the proportional epsilon adjustment was made and the statistical significance of the proportionally adjusted test was used.

Results

Baseline Measures

The baseline measures of heart rate and heart rate variability were analyzed with a multivariate ANOVA with testing age as a factor to assess the presence of preexisting differences in these between-subjects factor. There was a significant main effect of testing age on the multiple dependent variables, Wilks Lambda = .6639, F(8/96) = 2.73, p<.01. Table 1 presents the univariate means of the baseline variables for each age along with the significance of the individual one-way ANOVAs for those variables. The decrease in heart rate over this age was assessed with an epsilon-adjusted test was used.

Table 1

<table>
<thead>
<tr>
<th>Ages</th>
<th>HR Variance</th>
<th>Arhythmia Variance</th>
<th>Extent of Variability</th>
<th>Coherence</th>
<th>Weighted Arhythmia Coherence</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 weeks</td>
<td>155.0</td>
<td>3.97</td>
<td>1.82</td>
<td>.43</td>
<td>(0.47)</td>
</tr>
<tr>
<td>20 weeks</td>
<td>149.4</td>
<td>3.85</td>
<td>2.16</td>
<td>.47</td>
<td>(0.56)</td>
</tr>
<tr>
<td>26 weeks</td>
<td>147.3</td>
<td>3.91</td>
<td>3.26</td>
<td>.54</td>
<td>(0.60)</td>
</tr>
</tbody>
</table>

Infant Control and Interrupted Stimulus Presentations

Fixation Duration. The duration of the fixation during the presentations of the primary stimuli was analyzed with an Age(3) X Procedure(2) X Blinking Category(2) X Complexity(3) ANOVA. There was a significant main effect of testing age, F(2/54) = 17.54, p<.01. Infants at 14 weeks of age looked at the stimulus for the longest duration (12.5 s), at 20 weeks for an intermediate duration (8.3 s), and at 26 weeks for the shortest duration (7.0 s). There was a main effect of the type of procedure, F(1/51) = 6.02, p<.01. The duration of looking in the trials using the infant control method was longer than in those using the interrupted stimulus method (9.9 s compared with 8.0 s). There were statistically significant main effects for the blinking/non-blinking factor (F(1/51) = 8.86, p<.01), and for the stimulus complexity level (F(2/102) = 5.50, p<.01). Infants looked longer at the blinking (mean = 9.9 s) than at the continuously presented checks (mean = 8.9 s). The means on the low, medium, and high complexity checkerboards were 9.08 s, 10.7 s, and 8.6 s, respectively. However, the differences resulting from these two factors are not of direct interest to the experimental questions because they do not interact with procedure or age. The procedure X complexity and the age X procedure X blinking factor (F(2/102) = 4.19, p<.05) had a significant main effect. The differences among the three complexity levels were statistically significant after adjustment by the Greenhouse and Geisser method. There was a significant main effect of the epsilon adjustment was made.

Heart Rate Change. Heart rate was analyzed as the difference between the mean level of heart rate during the entire fixation period and the mean heart rate level during the 5 seconds preceding fixation, with an Age(3) X Procedure(2) X Blinking X Complexity(3) ANOVA. The only significant effect on the heart rate response was the age X procedure interaction, F(2/102) = 4.19, p<.05. A simple main effects analysis was used to test the difference between the three age groups separately for the infant control and the interrupted stimulus trials. The mean heart rate responses of the three age groups on the infant control trials were statistically different (p<.05). There were approximately equal differences among the three groups, with the 14-week-olds showing the least decrease over this age period. The correlations between the baseline variables are also presented in Table 1.

Infant Sustained Attention

The 0.5-s by 0.5-s changes illustrated in Figure 1 were not statistically analyzed because of the differing lengths of the individual trials due to the use of infant-determined presentation lengths. However, developmental trends in heart rate responses after the first 5 seconds of fixation were examined statistically by calculating heart rate change from the prestimulus level for the first 5 seconds of fixation (short latency) and for heart rate change in the second 5 seconds (long latency). Since many trials were less than 3 seconds in length, the short and long latency heart rate changes were taken from any trial over 5 seconds in length and the mean of those trials was computed for each subject separately for the two procedures. All subjects had at least one trial that met this criterion from the two procedures, and the overall percentages of these trials were 62%, 45%, and 41% for the 14, 20, and 26 week old groups, respectively. The differing percentages were consistent with the differences in visual fixation duration reported earlier. Although some of the long latency means were computed on trials of less than 10 s duration, these trials were included based on the assumption that the attention processes occurring during the second 5 seconds were different from those occurring in the first 5 seconds regardless of total fixation duration.

The heart rate change for the short and long latency phases was analyzed with an Age(3) X Procedure(2) X Phase interaction and a significant interaction of the short and long latency ANOVA. The procedure X phase interaction significantly affected the heart rate variable, F(1/51) = 8.17, p<.01. Heart rate increased from the short to the long latency periods for the infant control trials (−3.10 bpm to −1.65 bpm, respectively) but decreased from the short to the long latency periods for the interrupted stimulus trials (−2.93 bpm to −3.49 bpm). However, a more important significant interaction that affected heart rate was the age X procedure X phase effect, F(2/51) = 5.25, p<.01. Post hoc comparisons revealed the absence of an age X phase effect for the infant control trials, and a significant age X phase effect for the interrupted stimulus trials (p<.05). The heart rate increased from the short to the long latency periods for all three ages in the infant control trials (Figure 2A), whereas heart rate level in the interrupted stimulus trials increased for the 14-week-olds, and decreased for the 20 and 26 week olds (Figure 2B).

Correlation of Responses with Baseline Heart Rate Variability

Fixation Duration. The correlations between the baseline measures and visual fixation duration are
Table 2

Correlations between baseline heart rate variability and visual fixation and heart rate responses during visual attention for all subjects in the different experimental techniques

<table>
<thead>
<tr>
<th>Correlations</th>
<th>Experimental Techniques</th>
<th>HR Extent of Sinus Arhythmia</th>
<th>Weighted Coherence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infant Control</td>
<td>-090 ~ -195</td>
<td>-.053</td>
</tr>
<tr>
<td></td>
<td>Interrupted Stimulus</td>
<td>-041 ~ -084</td>
<td>-.034</td>
</tr>
<tr>
<td></td>
<td>Both Procedures</td>
<td>-061 ~ -183</td>
<td>-.062</td>
</tr>
</tbody>
</table>


Heart Rate Change

The correlations between heart rate change over the entire fixation period and the baseline measures of heart rate variability are presented in Table 2 separately for each procedure, and combined. The extent of sinus arrhythmia was significantly correlated with the heart rate change (short latency) and the second 5 seconds of fixation (long latency) for 14, 20, and 26 week old infants during the habituation sequence, attributing his finding to a more rigorous control of behavioral state during testing. Those studies that have used visual stimuli (e.g., Lewis, Kagan, Campbell, & Kalafat, 1966; Lewis & Spaulding, 1967) have typically been limited to a single age and reported only the results for mean of the several extreme bases. Thus, there were no precedents for expecting what should happen developmentally to the heart rate response to visual stimuli over this age range. The average maximum deceleration in the present study was about 6 to 7 bpm for all age groups, comparable to the Berg results. The average maximum heart rate response for the three familiarization trials with the secondary stimulus (not reported in results) was approximately 11 bpm for all three ages, almost identical to the levels reported by Berg (1974). The present results suggest that the findings of Richards (1985) of an accelerative response for 14-week-olds to similar stimuli, and the weak decelerative response for the 20-week-old infants in that study, resulted from an accelerative response accompanying the head movement toward the stimulus due to the methodology used in that study.

There was an important developmental trend found in the sustained attention responses during fixation. The youngest infants showed nearly identical patterns of heart rate responses for the infant control and the interrupted stimuli trials. The 20 and 26 week olds showed a pattern of heart rate on the 0.5-1.5 Hz range similar to the 14-week-olds only for the infant control trials. On the other hand, the initial heart rate decelerations during the interrupted stimuli trials were increasingly sustained for the 20 and 26 week old infants. Identifying these long latency responses as "sustained attention" implies that there is an increase in sustained attention over this age period. Since the interrupted stimuli procedure is a measure of the active allocation of processing resources, this could be thought of as an increase in the ability to direct attention to an interesting stimulus. Other investigators (e.g., Rose, 1983; Zelazo & Kearsley, 1982) have shown that over the first year of life infants increase in their ability to process information quickly. This finding is consistent with the shorter fixation durations of the older infants in this study and in Richards (1985). Thus, not only are infants able to process information more quickly with increasing age, they also show better attention processes (e.g., more sustained heart rate responses) as they get older. The present results imply that these increases in processing efficiency and quicker processing times may be due to developmental differences in the quality of attention directed toward visual stimuli.

REFERENCES

Anrep, G.W., Pascual, W., & Rondell, R. (1933). Respiratory variations of the heart rate. I. The reflex mech


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