# THE CYCLIC ORGANIZATION OF ATTENTION DURING HABITUATION IS RELATED TO INFANTS' INFORMATION PROCESSING

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We examined relations between one pattern of attention regulation-the cyclic organization of attention during information processing- and infants' processing speed and recognition memory. Twenty three-month-old and 20 six-month-old infants were assessed with an infant-control habituation procedure. Attentive states were coded frame-by-frame and subjected to time-series analysis. Processing speed was measured by infants' cumulative looking time to criterion and memory was indexed by responsiveness to novel stimulus following habituation. Infants whose attention was regulated in cyclic oscillations of attention and non-attention had shorter looking time and higher response to novelty. The relative proportion of transitory states and the number of cyclic peaks in the power spectra predicted processing speed but not memory. The relations between cyclicity and processing speed declined from 3 to 6 months. The regulation of attention in recurrent patterns is considered a correlate of efficient processing during the early stages of perceptual development.

**cyclicity habituation attention information processing**

Converging findings from different laboratories using different methods suggest that infants' performance on visual habituation and novelty responsiveness tasks is related to domains of cognitive functioning in later childhood and adolescence (McCall & Carriger, 1993; Rose & Feldman, 1995; Sigman, Cohen, & Beckwith, 1997). As the continuity between early visual processing and later cognitive competence has been validated across laboratories,

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researchers shifted the focus from substantiating this continuity to understanding its mechanisms. Several hypotheses emerged. These considered the meaning of "continuity" in mental development (Bornstein & Sigman, 1986), the similarities and differences between infants' and children's cognition (Lecuyer, 1989), and the mechanisms that are tapped by information processing tasks in infancy and intelligence tests in later childhood (McCall, 1994).

The link between early habituation performance and later cognitive competence has most often been attributed to individual differences in processing speed. "Short lookers," infants who require less time to habituate to a visual stimulus or shorter familiarization periods to recognize novelty, were thought to be those who are quicker to perceive, encode, structure, and memorize novel visual information. Shorter fixation durations were therefore considered to index more efficient information processing systems (Colombo, Mitchell, Coldren, & Freeseman, 1991; Slater, 1995). The reliability of looking time over repeated testing was taken to further support the hypothesis that processing speed is both a stable component of infant attention and a meaningful parameter of cognitive development (Colombo, Mitchell, O'Brien, & Horowitz, 1986).

Recently, however, several investigators have questioned the position that processing speed is the central explanatory variable. Recent studies suggest that while speed may explain some of the variability in both infants' information processing and children's cognitive abilities, it is one among several processes underlying mental development, memory being an equally important component of information processing. In a factor analysis on a battery of developmental, information processing, and cognitive tasks, Jacobson and colleagues (1992) found that speed and memory contributed independently to the total variability and suggested that information processing is the end result of different, interactive functions. Bornstein and Tamis-LeMonda (1994) showed that speed and memory were moderately related at 5 months and were each predicted by maternal and infant measures at 2 months while the other function was covaried. Rose and Feldman (1997), examining relations between information processing at 6 and 12 months and cognition at 11 years, found independent direct and indirect paths between speed and memory in infancy and later cognitive abilities. Speed and memory were both central to the prediction of later cognition and the link between the infancy measures and later IQ significantly decreased when speed and memory were controlled.

Processing speed itself may be a multifactorial function. Specifically, the orientation, inhibition, and disinhibition of attention have been suggested as essential components of processing speed. McCall (1994) argues that "short lookers" are not quicker to process new information but are better able to inhibit attention to a stimulus once encoded and, therefore, inhibitory mechanisms are the underlying cause for the continuity in mental development. Similarly, several investigators have focused on capacities to regulate attention, to limit input, and to disengage attention as the mechanisms underlying processing speed, efficient information processing, and learning (Dempster, 1990; Ruff & Rothbart, 1996; Sigman, Cohen, Beckwith, & Parmelee, 1986; Turkewitz & Kenny, 1982). Although these authors do not describe specific patterns of attention regulation, they share the view that the regulation of arousal into periods of information intake and states of limitation on input is conducive to efficient processing and perhaps mediate the development of cognitive competencies. Empirical support for the function of attention regulation in the development of cognitive competence comes from Sigman, Cohen, and Beckwith's (1997) recent followup. Longitudinal correlations were found between infants' fixation durations and cognitive tasks at 18 years that required the inhibition and shifting of attention but not with those measuring sustained attention, suggesting that the continuity in mental performance may be specifically related to processes of attention regulation and state control.

The cyclic organization of attention in periods of inhibition and disinhibition of attention resembles the cyclic organization of physiological periodicities. The organization of behavior in cycles of activity and rest has long been known as a regulatory mechanism of physiological and behavioral systems (Hebb, 1949; Schnierla, 1957; Wolff, 1967). Hidden in the newborn's seemingly random behavior, such as sleep and vigilance, respiratory sinus variation in heart rate, motility, sucking, and crying are several oscillators ranging from those of very fast periods, such as electrical cortical activity cycling in milliseconds to those of very slow periods, such as seasonal variations in the release of certain hormones. The central function of oscillators is to maintain balance between mechanisms that raise the level of systemic activity and mechanisms that control the inhibition of activity. From an evolutionary perspective, oscillators function to conserve energy, maintain highly stereotyped communicative signals, and facilitate the emergence of new forms of behaviors (Stratton, 1982; Thelen, 1979; Winfree, 1980; Zeskind, Goff, & Marshall, 1991).

There is evidence suggesting that cyclicity in the neonatal period and during the first months of life is related to cognitive performance in childhood. Thoman, Denenberg, Sievel, Zeidner, and Becker (1981) found relations between sleep-wake cyclicity in the first month and cognitive functioning at 6 to 30 months. Feldman, Greenbaum, Yirmiya, and Mayes (1996) showed that the cyclic organization of infant attention during mother-infant face-to-face play at 3 months, but not at 9 months, predicted IQ at two years. It was suggested that at 3 months, before infants develop voluntary control over the inhibition of attention (Johnson, Posner, & Rothbart, 1991), inborn periodicities expressed in the cyclic regulation of attention may be related to efficient information processing and later cognitive abilities. Doussard-Roosevelt, Porges, Scanlon, Alemi, and Scanlon (1997) showed longitudinal relations between vagal tone in preterm infants, the respiratory cycle in heart rhythms, and intelligence at 3 years. Cyclicity, being one regulatory pattern of the attention system (Dahl, 1996), may thus be related to the efficiency and speed of the infant's information processing.

In this study we examine the relations between the cyclic regulation of attention during information processing and the efficiency of information processing in terms of processing speed and visual memory in three- and six-month old infants. The cyclic regulation of attention implies that while confronted with novel visual information infants' attention oscillates between micro-states of attention and non-attention. This pattern, therefore, refers to the temporal regulation of attention in periods of information intake and states of limitation on input. In order to assess the unique contribution of cyclicity to information processing, we adapted Thoman's (1986) perspective on the development of state regulation. According to this perspective, the emergence of a mature distribution of states, that is, decrease in the prevalence of transitory states and increase in clear periods of sleep and alertness, precedes the development of state cyclicity. Thus, the proportion of transitory states in the infant's time-series and the cyclical organization of attentive states were examined as independent contributors to processing speed and memory. Infants were assessed with an infant-control habituation paradigm and attentive states during the habituation phase of the procedure were coded frame-by-frame. Series of attentive states were subjected to time-series analysis to detect underlying cyclicity. We expected that the cyclic organization of attention, particularly at 3 months, would be related to shorter duration to reach habituation criterion and to higher visual recognition memory.

## METHOD

### Participants

Forty infants, 20 at three and 20 at six months, were recruited from birth announcements in a local newspaper in New Haven CT. Postcards were mailed to families listed in birth announcements and between 30% and 40% of the families returned the post-cards, resulting in a self-selective sample. Infants were full-term, appropriate weight for gestational age, and with no perinatal complications. The sample included 21 girls (52.5%) and 19 boys whose mean age was 95 days at 3 months ($SD$ = 14.71) and 189 days at 6 months ($SD$ = 19.32). Infants and their parents were white, all parents had completed high-school, 90% had some college, and 70% had graduated college. All were middle to upper-middle class socioeconomic level based on education and income.

## Procedure

Assessment took place in a semi-enclosed booth measuring 1.2 m x 2.75 m. Infants sat in an infant-seat situated 60 cm from a white matte screen. The infant-seat was adjusted to a 30 degree visual angle and the slides were projected onto the screen above the infant's head. The infant's face was recorded by a videocamera located in a 10 cm hole placed at the infant eye level in the screen.

Infants were tested with an infant-control habituation paradigm. In this paradigm infants are tested repeatedly until a predetermined habituation criterion is reached. Criterion was defined as two consecutive looks with duration equal or lower than 50% of the baseline, which was considered the mean duration of the first two looks. Trials begin when the infant looks ahead and end when the infant looks away. A look was defined as a gaze of at least 0.2 s and look away as minimally 0.5 s. Sessions began with a warm-up phase in which a brightly colored geometric pattern appeared on the screen. Next, the habituation stimulus, a photograph of an affectively neutral female's face, was presented. Following the habituation phase, a novel stimulus was presented paired with the habituation stimulus and last, the warm-up stimulus was presented again. The same two sets of pictures were used at 3 and at 6 months; at each session one of two sets of stimuli were randomly chosen.

## Measures

### Quantitative and Derived Measures of Habituation

Three quantitative measures of habituation were derived from the infant's looking behavior toward the habituation stimulus: (1) Length of Peak Look defined as the longest look before habituation criterion was reached; (2) Cumulative Looking Time defined as the accumulated looking time including the criterion look; and (3) Number of Looks before criterion is reached. Cumulative looking time and length of peak look have shown moderate stability over repeated testing (Bornstein, Pecheux, & Lecuyer, 1988; Colombo et al., 1986) and the number of looks to criterion has shown mean-level continuity from 3 to 6 months (Mayes & Kessen, 1989). These measures may tap a relatively stable component of infant attention and were therefore selected for this study. Two other quantitative measures were used to describe habituation. Slope was computed by fitting linear regression functions to each infant's series of looks during habituation in seconds (Benasich & Tallal, 1996). Visual Recognition Memory (VRM) was measured following Fagen (1970) as the percent of responsiveness to the novel stimulus in comparison to the familiar habituation stimulus. These measures have been associated with the efficiency of information processing and with cognitive development (Tamis-LeMonda & Bornstein, 1989).

### Microanalysis of Attentive States

Frame-by-frame analysis of attentive states was conducted for each 0.10 s interval. States were mutually exclusive, ranged from negative to positive arousal, and included the following codes: (a) *High Negative Arousal-Fuss/Cry*—infant is in a state of negative arousal, crying, or fussing; (b) *Drowse*—eyes closed, "heavy lidded," or open but dazed; (c) *Gaze Aversion*—gaze is unfocused, eyes are turned away from the stimulus but are not fixed on other stimuli. Facial expression is weary or relaxed; (d) *Transition*—This state is indicated by behaviors of both aversion and attention. Infant is in a process of shifting to or from focused attention, head or gaze is turning toward or away from the stimulus, eyes are refocused or loose focus, and facial expression brightens or withdraws; (e) *Attention to the Habituation Stimulus*—infant's gaze is focused on the stimulus and facial expression is bright and intense; (f) *Attention to the Environment*—infant is attentive but attention is directed to elements of the environment, such as body parts, strap of the seat etc.; (g) *Positive Arousal*—while attending, infant demonstrates positive affect by smiling, vocalizing, or laughing towards the female's face on the screen.

## Coding

Coding of the habituation phase of the session was conducted frame-by-frame and entered for each 0.10 s. Coders first watched the habituation procedure when the tape was running in slow motion to determine the initiation and termination of the habituation phase. The habituation phase was then coded frame-by-frame and shifts of state were rounded to the nearest .10 s. Reliability was examined on six random sessions and reliability kappa was .83.

## Data Analysis

Each time-series of attentive states was analyzed in the frequency and time domains, two mathematically equivalent methods of time-series analysis (Gottman, 1981). Frequency-domain analysis is used to detect underlying cyclicity in a time-series by computing the spectral density function for a series and assessing whether peaks observed in the power spectra (the graphic display of the spectral density function) are reliably differentiated from white noise, that is, peaks are not artifacts of random change over time. Spectral density functions were computed for each time-series by smoothing the periodogram with a Tukey-Hamming window set at a conservative size of 10% of the time-series. Peaks observed in the power spectra were considered to indicate cyclic oscillations when the 95% confidence interval was above the theoretical distribution of white noise as measured by the Kolmogorov-Smirnov test (Jenkins & Watts, 1968).

Spectral analysis yielded three variables. (1) Cyclicity—this binary variable indexed whether the time-series was underlaid by cyclic oscillations. A value of 1 was assigned when at least one reliable peak was observed in the power spectra. (2) Power of the Basic Cycle—assessed the amplitude of the main cycle in the power spectra. The cycle with the highest amplitude was considered the main cycle when more than one cycle was detected. (3) Number of Cycles—the number of reliable peaks observed in the power spectra. This variable examines whether a time-series is underlay by one or several cycles. Although our main interest was the relation between cyclicity and information processing, the Power of Basic Cycle and the Number of Cycles were included to examine whether specific characteristics of the cyclic organization add unique variance to the prediction of speed and memory, above and beyond the existence of cyclic oscillations.

Following the frequency-domain analysis, time-series were analyzed again in the time domain by fitting ARIMA (Autoregressive Integrated Moving Average) models to each time-series. These analyses enabled the assessment of underlying organization of series that were not cyclic. ARIMA modelling involved three stages. In the first, the autocorrelation (ACF) and partial autocorrelation (PACF) functions were plotted. The ACF and the PACF point to the underlying organization of the time-series. Second, a best-fitted model was estimated for the time-series. Finally, the residuals of the estimated time-series were checked with the Box-Ljung $Q$ statistic for lack of autocorrelations. This indicates that the residuals are distributed as white noise and validates the estimated model.

## *RESULTS*

## *The Cyclic Organization of Attention*

### *1. Frequency-Domain Analysis*

Spectral analysis conducted on the 40 time-series showed cyclic peaks that departed from white noise for 12 out of 20 infants at 3 months (60%) and for six out of 20 infants at 6 months (30%). The main reliable peak at both 3 and 6 months was observed in the frequency band of .04-.09 Hz, indicating a period between one cycle every 2.5 s (24 cpm) and one cycle every 1.1 s (54 cpm). In cases when more than one cyclic peak was observed, the second peak was observed in the frequency band between .16 and .18 Hz, a rhythm ranging from one cycle every .625 s (96 cpm) to one cycle every .55 s (109 cpm). This high-frequency cycle typically occurs within a single gaze and is unnoticed when the tape is running in normal speed. In cases of three or four peaks, the third and fourth peaks were observed between the lower (.04 - .09 Hz) and higher (.16 - .18 Hz) frequencies.

At 3 months, all infants whose attention was organized in a cyclic pattern showed at least two reliable peaks in the power spectra. Eight infants showed two peaks, three infants showed three peaks, and one infant showed as many as four reliable peaks in the power spectra. At 6 months, two infants showed two reliable peaks in the power spectra, one in each frequency band, and the other four infants showed one peak in the lower frequency. Age related changes in measures of cyclicity are examined below.

### *2. Time-Domain Analysis*

ARIMA models conducted on the 40 time-series revealed that all series had a significant autocorrelated component of the first or second order (AR1 or AR2). These autocorrelated processes indicate that attentive states are predicted from the immediately preceding one (AR1) or two (AR2) states. Time-series that were cyclic were fit by an AR2 process that fit the following; $a_1^2 + 4a_2 < 0$, when $a_1$ and $a_2$ are the two autoregressive parameters (Gottman, 1981). Results of the time-domain analyses suggest that the cyclicity of attention found here can be described as *stochastic cyclicity,* which refers to a probabilistic, rather than deterministic cyclic organization. In the present context, stochastic cyclicity implies that although attention cycles between micro-states of attention and non-attention, cycles do not reoccur in precise intervals and only approximate those of physiological periodicities (Cohn & Tronick, 1988).

The eight non-cyclic series at 3 months were fit by an autocorrelated process of the first order (AR1). Four of the time-series at 6 months were fit by an autocorrelated process of the second order (AR2) that was non-cyclic (as indicated by area of stationarity). The 10 remaining series at 6 months were fit by an autoregressive (AR) combined with a moving average (MA) process, a process indicated by slowly decaying peaks on both the ACF (indicating AR process) and the PACF (indicating MA process) plots. This process implies that although attentive states are generally autocorrelated and each state is predicted by the immediately preceding state, series also incorporate perturbations (non-autocorrelated turns in the time-series) into the stream of behavior.

## *Developmental Changes*

Age-related changes were computed for the quantitative and derived measures of habituation, the distribution of attentive states, and measures of cyclicity. Means, standard deviations, and *F* values of univariate analysis of variance are presented in Table 1. No gender effects were found and data were collapsed across gender.

TABLE 1
Developmental Changes in Measures of Habituation, State Distribution, and Cyclicity

| | *3 Months* | | *6 Months* | | |
|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *F* |
| *A: Measures of Habituation* | | | | | |
| Cumulative Looking Time in s | 30.15 | 7.44 | 26.87 | 6.12 | 3.86+ |
| Length of Peak Look in s | 9.89 | 6.36 | 7.32 | 3.14 | NS |
| Number of Looks to Criterion | 7.71 | 3.01 | 6.38 | 3.79 | NS |
| Slope (%) | -24.73 | 36.68 | -31.84 | 34.40 | NS |
| VRM (% novelty) | 50.31 | 18.15 | 61.84 | 17.91 | 3.91+ |
| *B: Distribution of Attentive States* | | | | | |
| Negative Arousal | .05 | .12 | .08 | .14 | .50 |
| Drowsy | .11 | .12 | .01 | .02 | 13.73*** |
| Gaze Aversion | .48 | .17 | .43 | .19 | .75 |
| Transition | .15 | .04 | .07 | .005 | 46.85*** |
| Attention to Stimulus | .33 | .12 | .37 | .14 | .81 |
| Attention to Environment | .02 | .06 | .19 | .24 | 9.61** |
| Positive Arousal | .02 | .05 | .02 | .04 | .15 |
| *C: Cyclicity of Attention* | | | | | |
| Proportion of Series with Reliable Peaks in Power Spectra | .60 | .47 | .30 | .41 | 3.99* |
| Number of Cycles | 2.36 | .67 | 1.60 | .54 | 4.88* |
| Slowest Cycle (cpm) | 31.56 | 10.66 | 29.50 | 7.54 | .11 |
| Fastest Cycle (cpm) | 99.50 | 16.08 | 97.50 | 14.40 | .03 |
| Power of Basic Cycle | 296.36 | 209.15 | 204.00 | 157.25 | .76 |

+$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$

As seen in Table 1, Cumulative Looking Time decreased and Visual Recognition Memory increased from 3 to 6 months but these changes were only marginally significant. Infants required shorter durations to habituate to a visual stimulus and showed higher response to novelty at 6, as compared to 3 months. None of the other quantitative or derived measures of habituation—Number of Looks to criterion, Slope, or Length of Peak Look -changed significantly with age. The percentage of response to novelty at 3 months did not differ from chance, $t\ (1, 19) = 0.13$, *ns*. At 6 months, novelty responsiveness differed marginally from chance $t\ (1, 19) = 1.\ 71$, $p = .053$.

Age-related changes were also observed in the distribution of states. The proportion of Transition and Drowsy states decreased and Attention to the Environment increased with age. The proportion of Attention to the Habituation stimulus and Gaze Aversion, states directly involved with information intake and the inhibition of attention, did not change with age and in combination these states occupied most of the habituation period; 81% and 80% at 3 and 6 months respectively. Developmental changes were found for the cyclicity measures as well. The proportion of series showing cyclic organization and the Number of Cycles decreased with age. No changes were observed for the Power of the Basic Cycle and the periods (cpm) of the slowest and fastest cycles.

## *Cyclicity Effects*

The effects of cyclicity on measures of habituation and distribution of states were examined with multivariate analysis of variance (MANOVA) with age and cyclicity as between-subject factors. As previously described, cyclicity was used as a binary variable with 12 of the 20 infants at 3 months and 6 of the 20 infants at 6 months scoring 1 for cyclicity. MANOVA conducted on the qualitative and derived measures of habituation showed no overall effect for age, an overall

TABLE 2
Measures of Habituation in Cyclic and Non-Cyclic Infants

| | Cyclic (N = 18) | | Non-Cyclic (N = 22) | | |
|---|---|---|---|---|---|
| | M | SD | M | SD | F |
| Cumulative Looking Time in s | 25.19 | 5.95 | 30.60 | 6.75 | 7.01** |
| Length of Peak Look in s | 9.31 | 5.23 | 8.18 | 5.31 | NS |
| Number of Looks to Criterion | 7.38 | 3.29 | 8.57 | 3.45 | NS |
| Slope (%) | -40.07 | 35.96 | -18.97 | 30.77 | 5.25* |
| VRM (% novelty) | 67.37 | 13.14 | 47.22 | 17.94 | 12.51*** |

*p < .05, **p < .01, ***p < .001

effect for cyclicity, $F(5, 32) = 4.78, p = .002$, and a marginal age by cyclicity interaction $F(5, 32) = 2.26, p = .073$. These findings suggest a that infants whose attention was cyclic showed a different pattern of information processing on the qualitative and derived measures of habituation and that the relationships between cyclicity and measures of habituation tended to decrease with age. Results of the univariate analyses are presented in Table 2.

Results reported in Table 2 show that infants whose attention was cyclic had shorter Cumulative Looking Time, steeper Slope, and higher Visual Recognition Memory. No cyclicity effects were found for the Number of Looks to criterion or the Length of Peak Look. Univariate analysis of the interaction showed significant age by cyclicity interaction for Cumulative Looking Time only, $F(1, 36) = 4.41, p < .05$, indicating that with age the relations between cyclicity and looking-time decreases.

Multivariate analysis of variance with age and cyclicity as the between-subject factors conducted for the distribution of states revealed an overall effect for age $F(5, 32) = 7.36$, $p < .001$, no overall effect for cyclicity, and an overall interaction, $F(5, 32) = 4.01$, $p = .003$. Univariate tests for cyclicity showed significant results for Transition only, $F(1, 36) = 4.41, p < .05$, indicating that cyclic infants spent less time in Transition states. Univariate analysis of the interaction showed significant age by cyclicity interaction for Transition, $F(1, 36) = 6.41, p < .001$. This indicates that the differences between cyclic and non-cyclic infants on the frequency of transition was higher at 3, as compared to 6 months.

## *Predicting Processing Speed and Memory*

Two hierarchical regression equations were computed to predict Cumulative Looking Time and Visual Recognition Memory. Cumulative Looking Time and Visual Recognition Memory were negatively correlated, $r = -.44$, $p < .01$, finding in line with previous research (Bornstein & Tamis-LeMonda, 1994). In each equation predicting speed or memory, age was entered first to control for developmental trends and the other function was entered in the second step to control for the covariation of speed and memory. Following, measures of state regulation were entered. The proportion of Transition states was entered prior to Cyclicity of Attention in light of their hypothesized sequential development. The Power of Basic Cycle and the Number of Cycles were then entered to examine their unique contribution to speed and memory.

Results reported in Table 3 indicate that age, higher VRM, lower frequencies of Transition, Cyclicity of Attention, and the Number of Cycles each accounted for unique variance in Cumulative Looking Time and predicted shorter fixation durations. Processing speed, therefore, appears to have independent relations to the two aspects of state regulation—the mature distribution of states and the on-line regulation of attention. With regard to Visual Recognition Memory, age, shorter Cumulative Looking Time, and Cyclicity of Attention

TABLE 3
Predicting Cumulative Looking Time and Visual Recognition Memory

| | *Beta* | *MR* | *Adj R* | $R^2$*Change* | *FChange* |
|---|---|---|---|---|---|
| Criterion: Cumulative Looking Time | | | | | |
| *Predictors* | | | | | |
| Age | -.29 | .27 | .06 | .07 | 2.98+ |
| Visual Recognition Memory | -.20 | .44 | .18 | .16 | 4.23* |
| Proportion of Transition States | .19 | .58 | .28 | .11 | 6.11** |
| Cyclicity of Attention | -.41 | .63 | .32 | .06 | 3.37* |
| Power of Basic Cycle | .11 | .63 | .30 | .00 | NS |
| Number of Cycles | -.83 | .71 | .41 | .10 | 6.67** |
| $R^2$ Total= .50, F (6, 32) = 5.34, *p* = .0007. | | | | | |
| Criterion: Visual Recognition Memory | | | | | |
| *Predictors* | | | | | |
| Age | .27 | .31 | .07 | .09 | 3.04+ |
| Cumulative Looking Time | -.25 | .54 | .25 | .20 | 7.26** |
| Proportion of Transition States | .08 | .55 | .24 | .01 | NS |
| Cyclicity of Attention | .23 | .60 | .30 | .07 | 4.17* |
| Power of Basic Cycle | .19 | .62 | .29 | .02 | NS |
| Number of Cycles | .05 | .62 | .26 | .00 | NS |
| $R^2$ Total= .39, F (6, 32) = 3.27, *p* = .011. | | | | | |

+*p* < .10, **p* < .05, ***p* < .01

were each independently related to VRM. Unlike the findings for speed, the proportion of Transition and the number of cycles did not account for unique variance in VRM. However, because the number of predictors (6) is high in relation to sample size (n = 40), the results should be interpreted with caution and merit further research.

## DISCUSSION

The relations between the efficiency of information processing and the temporal organization of attentive states were examined in three- and six-month old infants. Results indicated that the regulation of attention in a cyclical pattern is a correlate of efficient information processing in terms of speed and memory, particularly among three-month old infants. The cyclic organization of attention implies that during the processing of novel visual information infants' attention cycles between micro-states of attention and non-attention in a relatively regular pattern. Infants whose attention was cyclic required less time to reach habituation criterion, showed a more efficient global pattern of looks as measured by the slope of looking times, and demonstrated higher response to novelty. These functions; efficiency of processing, inhibition of attention, and responsiveness to novelty, have been recognized as central components of the construct of intelligence and as related to the continuity in mental performance from infancy (Berg & Sternberg, 1985; Bornstein & Sigman, 1986; Ceci, 1990; Dempster, 1990; McCall, 1994). Although causal relationships between cyclicity and information processing have not been demonstrated, the results add to the body of literature on the relations between state regulation and the development of cognitive competencies (Lecuyer, 1989; Sigman et al., 1986).

Developmental changes were observed for cyclicity, measures of habituation, and the relations of processing speed and cyclicity between 3 and 6 months. The proportion of cyclic time-series decreased with age; the amount of looking time to criterion decreased and the percentage of novelty recognition increased; and the relations between cyclicity and looking time became weaker at 6, as compared to 3 months. Thus, if cyclicity is one regulatory pattern of the attentional system (e.g., Dahl, 1996; Thoman, 1986), its prevalence during the processing of novel information appears to decrease with age. In general, periods of cyclic organization typically accompany the evolution of systems and are observed primarily during periods of rapid systemic growth (Stratton, 1982; Thelen, 1979). Research has demonstrated links between various cyclical functions, such as sleep-wake cyclicity, respiratory cycles, and cyclicity of attention, during the first weeks of life and cognitive development, but the prediction from measures of cyclicity decreases after the first months of life (Doussard-Roosevelt et al., 1997; Feldman et al., 1996; Thoman et al., 1981). Turkewitz and Kenny (1982) suggest that the organization of information in regular periods of information intake and states of limitation on input is crucial for information processing during the developmental stages of immature perceptual systems but the significance of involuntary inhibitory mechanisms declines as perceptual systems mature and develop more sophisticated means of control. At 3 months the visual system undergoes rapid development but infants are not yet capable of voluntary controlling the inhibition and disinhibition of attention. At 4 months infants gain voluntary control of attention with the growing ability to disengage gaze from a stimulus (Johnson, Posner, & Rothbart, 1991). At this point, a different temporal organization of attentive states may emerge, as indicated in the data by the increase in the number of time-series underlay by an autocorrelated and moving average process at 6 months and the decrease in cyclic time-series.

Cyclicity of attention independently predicted processing speed and memory when the other function was controlled. This suggests that the relations of cyclicity and information processing may not be related to the shared variance of speed and memory. While these correlational data do not address mechanisms, one possibly relevant conceptual framework is that of oscillator mechanisms. As suggested by several investigators (Porges, 1995; Statton, 1982; Winfree, 1980), oscillators are evolutionary conserved mammalian mechanisms which moderate the organism's adaptation to environmental inputs, and, as such, may be related to the infant's general orientation to the stimulus and to various components of information processing. Oscillators have also been linked with processes related to information processing such as arousal regulation, attention, and learning (Dahl, 1996). Furthermore, the renin-angiotensin system (RAS), which moderates physiological periodicities, has also been shown to play a role in information processing, memory, and recall (Wright & Harding, 1992). Cyclicity of may therefore be one regulatory process of attention which is related to the global efficiency of the information processing system.

Finally, differences, in addition to similarities, between physiological cycles and cycles of attention are important in the present context. These relate to differences in the degree of determinacy of periodic and stochastic cycles. Periodic cycles, observed in physiological systems, appear in predetermined regularity and in near precise intervals whereas stochastic cycles, which characterize order in behavioral or social systems, are non-deterministic and only approximate the regularity of physiological periodicities (Cohn & Tronick, 1988). Stochastic cycles, which were observed here, are flexible, emergent, and open to the changing influences of external events. The integration of determinacy and change afforded by stochastic-cyclic processes may be important in the context of attentional processes, particularly in the early stages of development. At 6 months, the autocorrelated and moving average process observed for half of the time-series is even less deterministic than the stochastic-cyclic process observed at 3 months. In such process, cycles of attention and non-attention are not observed and each attentive state emerges as either a function of the previous state or an uncorrelated, perhaps voluntary shift to a different level of arousal.

Interestingly, the data show a temporal link between physiological rhythms and the rhythm of attention. Cycles of attention during habituation were found here to last between 1 and 3 seconds, the same period as reported for respiratory sinus arrhythmia (RSA) in newborns (Clairambault, Curzi-Dascalova, Kauffmann, Medigue, & Leffler, 1992). Respiratory sinus arrhythmia is a measure that estimates the parasympathetic inhibitory control over heart rhythms. It has been shown to index sustained attention in infants (Richards, 1987) and serves as a physiological correlate of arousal regulation (Porges, 1995). As suggested by Wright and Harding (1992), the same neurobiological system may monitor cyclicity of cardiac activity and cyclicity of attention and the findings may highlight an additional angle in the relations between sustained attention and respiratory sinus arrhythmia.

Mechanisms of attention regulation, their impact on cognitive processes, and their growth and transformation over time require much further research. More information is needed on specific processes that control infant arousal during the performance of cognitive and attentional tasks and their relations with sub-functions of information processing. Mechanisms of attention regulation need to be defined in terms of their specific role in the development of competence, their interaction with physiological control mechanisms, and their contribution to individual differences in cognitive functioning as infants grow and master increasingly complex tasks.

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