The Effects of Attention and Processing Speed on Complex Rule Learning
The University of Tennessee, **Framingham State College, ***The Ohio State University

Abstract
The current study examined whether indices of attention and processing speed contributed to individual differences in the distribution and frequency of anticipatory responses to a complex spatial-temporal rule in the Visual Expectation Paradigm (VExP). High frequency heart period variability (HFHPV) was computed during a resting baseline session before infants viewed a repeating Left-Left-Right sequence in the VExP and completed a fixation duration task. Percent of anticipatory responses prior to each location in the sequence was computed. Infants were also categorized as either short or long looking on the fixation duration task and as either high or low on HFHPV. Analyses indicated that infants with high levels of resting HFHPV demonstrated the optimal pattern of anticipatory responding suggestive of rule learning. In contrast, infants with low levels of HFHPV tended to anticipate indiscriminately, with an equal percentage of both correct and incorrect anticipatory shifts. Contrary to the original hypotheses, the distribution of anticipatory responses did not vary by looking status or sex.

Introduction
Prior research using the VExP demonstrated that the frequency and pattern of infants’ anticipatory responses to rule-based patterns are influenced by the spatial complexity and predictability of the rule. Within these early studies, individual differences in anticipatory responding were overlooked even though it varied widely across infants. Despite our limited understanding of these individual differences or a clear definition of what constitutes successful or optimal performance, the VExP has repeatedly been used in studies predicting later cognitive functioning and in studies assessing at-risk infants.

The current study examined two issues. First, we identified three patterns of anticipatory responding that reflect varying levels of anticipatory utilization of a Left-Left-Right (L-L-R) rule: optimal, probability, and indiscriminant (see Figure 1). From these patterns, we developed a new composite variable to try capture the variance reflected in these anticipatory patterns and examined the relation between this new variable and standard VExP variables as well as infant and family characteristics.

Second, we examined cognitive processes that may influence individual differences in the patterning and rate of anticipatory responding. Both the ability to sustain attention and the infant’s processing speed are likely to influence this ability. Lapses in attention could prevent the infant from abstracting the rule or result in a high rate of errors. Similarly, slower processing could result in less optimal performance if pieces of the rule begin to degrade before the infant is able to integrate them to detect or use the rule. Thus, we hypothesized that lapses in attention and slower rates of processing would likely result in probability or indiscriminant patterns of anticipatory responding.

Hypotheses
- Overall, infants will display the optimal pattern of anticipatory responding, suggesting they learned the L-L-R rule.
- Infants with high resting levels of HFHPV, who are presumed to be better able to regulate their attention, will display the optimal pattern of anticipatory responding while infants with low resting levels of HFHPV will display the indiscriminant or probably pattern of responding.
- Infants classified as short looking will display the optimal pattern of anticipatory responding while infants classified as long longing, who are presumed to process information more slowly, will display the indiscriminant or probability pattern of responding.
- Boys will make more anticipatory shifts than girls.
- HFHPV, looking status, and sex will be significant predictors of the composite anticipation variable.

Terminology
Anticipatory Shift: An eye movement to a possible stimulus location during the inter-picture interval or within 200 ms of picture onset.
- Correct Anticipatory Shift: An eye-movement, within the anticipatory window, to the location of the upcoming stimulus
- Incorrect Anticipatory Shift: An eye-movement, within the anticipatory window, to a possible, but incorrect location. By definition, an incorrect shift can only occur when successive stimuli are presented in the same location.

Picture Locations: Denoted as H1 – H2 – T1. See Figure 2.

Inter-picture Interval (IPI): Elapsed time between the offset of one picture and the onset of the next picture.

High Frequency Heart Period Variability (HFHPV): The spectral power of the variability in time between heartbeats (heart period) in the frequencies of respiration. This variability is thought to primarily reflect changes in parasympathetic influences on heart-period.

Methods and Procedures
Participants (See Tables 1 &2)
- 109 13 week-old infants
  - 80 infants with valid VExP data
  - 71 % of excluded infants had low resting levels of HFHPV.

Visual Expectation Paradigm (See Figure 1):
- Baseline: 11 spatially and temporally irregular pictures
  - Interpicture Interval: Randomly varied between 750, 950, and 1150.
  - Picture Duration: Randomly varied between 500, 700, and 900.
- Postbaseline
  - 20 cycles of a repeating Left-Left-Right or Right-Right-Left sequence.
  - Interpicture Interval: 750 ms
  - Picture Duration: 700 ms

Data Reduction: Trained coders recorded the latency of infants reactive and anticipatory saccades to the picture locations using a VCR in single-frame advance mode.
- Anticipatory Shifting
  - Percent of shifting during baseline
  - Percent of anticipatory shifts to the H1, H2, and T1 locations during the postbaseline sequence. (See Figure 2)
Average Correct-Incorrect Shifting Difference (AveShDiff)

\[ ((H1 \text{ shifts} - H2 \text{ shifts}) + (T1 \text{ shifts} - H2 \text{ shifts})) / 2 \]

Attention Index: High Frequency Heart Period Variability (HFHPV)

- 5 minute resting baseline period assessed before other tasks
- Heart period digitized at 1000 Hz
- HFHPV calculated using natural log of spectral power band .24 – 1.04 Hz.
  - Artifact-free epochs of 25 second or longer included in FFT calculation
  - Weighted average power of epochs calculated in cases with greater than 1 epoch.
- Infants categorized as high or low on HFHPV using a median split.

Processing Speed: Fixation Duration

- Infants viewed a digitized color photograph of a woman’s face until they accumulated 30 seconds of looking time.
- Off-line computation of mean fixation duration and maximum fixation duration.
- Infants placed into short or long looking categories using a median split on the maximum fixation duration variable.

Results

Composite Anticipation Variable: AveShDiff

- Mean (SD): 3.78 (7.22)
- Range: -14.72 to 16.04
- See Table 3 for correlations.

Regression Model Predicting AveShDiff

- Step 1: Infant and family characteristics evaluated as predictors: sex, maternal education, gestational age, birth length, maternal age, breast feeding, age at test, birth weight, and cigarette exposure.
- Step 2: Log transformed HFHPV, maximum look duration evaluated as predictors.
- Step 3: Baseline RT, Predictable RT, Baseline Anticipation Rate
- Only LogHFHPV and Baseline RT were significant predictors of AveShDiff

<table>
<thead>
<tr>
<th>Predictors</th>
<th>B</th>
<th>SE  B</th>
<th>( \beta )</th>
<th>( \Delta R^2 )</th>
<th>df</th>
<th>( F_{\text{change}} )</th>
<th>Total ( R^2 )= .18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-8.45</td>
<td>1.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Adj ( R^2 )= .14</td>
</tr>
<tr>
<td>LogHFHPV</td>
<td>3.70</td>
<td>2.13</td>
<td>.22</td>
<td>.07</td>
<td>1, 53</td>
<td>4.03</td>
<td>( R = .42 )</td>
</tr>
<tr>
<td>Baseline RT</td>
<td>.02</td>
<td>.01</td>
<td>.33</td>
<td>.11</td>
<td>1, 52</td>
<td>6.60</td>
<td></td>
</tr>
</tbody>
</table>

The influence of HFHPV and sex on anticipatory shifting to each location was examined using a 2 (High vs. Low HFHPV) x 2 (sex) x 3 (H1, H2, T1) repeated measures ANOVA with baseline rating of shifting as a covariate.

- Baseline rate of shifting was a significant covariate, \( F(1, 55) = 14.14, p < .001 \).
- There was a significant quadratic effect for location, \( F(1, 55) = 5.55, p < .03 \).
  - Infants shifted more frequently to the correct locations (H1, T1) than to the incorrect location (H2).
- There was a significant main effect of HFHPV, \( F(1, 55) = 14.14, p < .01 \), and a quadratic location by HFHPV interaction, \( F(1, 55) = 7.98, p < .01 \). See Figure 6.
  - Infants with high resting levels of HFHPV displayed the expected pattern of anticipatory responding with a higher percentage of shifts to the correct H1 and T1 locations and fewer shifts to the incorrect H2 location.
  - Infants with low resting levels of HFHPV displayed an indiscriminant pattern of shifting with an approximately equal percentage of shifting prior to each of the three picture locations.
- There was no main effect of sex. The location by HFHPV by sex effect approached significance, \( p < .09 \).
The influence of looking status and sex on anticipatory shifting to each location was examined using a 2 (Short vs. Long Lookers) x 2 (sex) x 3 (H1, H2, T1) repeated measures ANOVA with baseline rating of shifting as a covariate.

- Baseline rate of shifting was a significant covariate, \( F(1, 51) = 7.122, p < .01 \).
- The quadratic location by sex effect approached significance, \( F(1, 51) = 3.43, p < .07 \).
  - Male infants tended to shift indiscriminately to the three locations.
  - Female infants tended to shift more frequently to the H1 and T1 locations and less frequently to the H2 location.
- There were no significant main or interaction effects of looking status on anticipatory shifting. See Figure 7.

Discussion

Attention and Anticipatory Responding: Infants with high resting levels of HFHPV distributed their anticipatory responses differently than infants with low resting levels.

- The anticipatory pattern of high HFHPV infants mirrored the spatial pattern of the rule providing evidence of learning.
- In contrast, low HFHPV infants tended to shift indiscriminately and their anticipatory data provided no evidence of rule learning.
- Low HFHPV infants were also significantly less likely to provide sufficient data on the VExP, although the exact reason behind their drop out is unknown.
- These data suggest that infants who exhibit lower levels of attentional control have difficulty abstracting predictability from their environment, even when presented with numerous repetitions.

Processing Speed and Anticipatory Responding: Neither the pattern nor the frequency of anticipations varied significantly by looking status, suggesting that how quickly or efficiently infants process information is not a predictor of spatial rule learning.

- One explanation for this is that infants do not need to learn anything about the visual content of the picture to succeed on this task. The critical information is the spatial location of the pictures and the order of presentation across the locations.
The dissociation between these measures is likely to help us understand what brain systems and cognitive processes contribute to anticipatory responding during early infancy.

- The new composite anticipation variable provides a single estimate of anticipatory evidence of complex rule learning and reflects not only the frequency of anticipatory responding but also the correct and incorrect distribution of anticipatory shifts.

- AveShDiff was highly correlated with both correct and incorrect shifting during the predictable sequence suggesting that it adequately represents both variables.

- The absence of a correlation between the baseline shifting and AveShDiff was surprising and suggests that the new composite variable is not simply measuring individual differences in activity rates or exploration and may be a better estimate of learning than typical anticipation measures.

- Surprisingly, AveShDiff was correlated with baseline RT. Correlations between RT and anticipations are typically low and non-significant.

- Future research needs to examine the reliability of this measure as well as its relation to other outcomes.

References