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Developmental Changes in Infant Attention to Dynamic and Static Stimuli

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This study examined 4- and 6-month-olds' responses to static or dynamic stimuli using behavioral and heart-rate-defined measures of attention. Infants looked longest to dynamic stimuli with an audio track and least to a static stimulus that was mute. Overall, look duration declined with age to the different stimuli. The amount of time spent in sustained attention at 4 months, but not at 6 months, was related to stimulus discrimination. These results indicate that the decline in look duration typically observed during the middle of the 1st year for static stimuli does generalize to dynamic stimuli. The results further suggest that the amount of time spent in sustained attention during habituation may be an important indicator of processing in younger infants.

The visual habituation paradigm has been the predominant technique for assessing cognitive function in preverbal infants, and among the major variables derived from this paradigm is the duration of looking (Colombo & Mitchell, 1990). Although the developmental course of look duration is nonlinear across infancy and toddlerhood (e.g., Colombo, 2000), the decline in look duration during the first year has been the focus of much recent research. This decline has been widely replicated (e.g., Colombo & Mitchell, 1990; Mayes & Kessen, 1989) and has supported the interpretation that it reflects an improvement in either processing efficiency (Colombo, Mitchell, Coldren, & Freeseman, 1991) or the disengagement of attention (e.g., Frick, Colombo, & Saxon, 1999). However, work showing this decline has been done almost exclusively with static visual stimuli; research with dynamic stimuli over the same age range has yielded less consistent findings (Burnham, Vignes, & Ihsen, 1988; Caron, Caron, & MacLean, 1988; Richards & Holley, 1999; Ruff, 1985). This

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challenges the generality of the developmental course and its interpretation. In fact, very few studies have directly compared infant attention to dynamic and static stimuli (see Malcuit, Pomerleau, & Beauregard, 1991), and none have examined differences in developmental changes across these stimulus types. This article attempts to address these conflicting results through the conduct of a cross-sectional study that directly compares the development of infants' look duration (measured with concomitant heart rate [HR] responses) to static and dynamic stimuli.

This article also addresses the relation between attention and cognitive performance. Using the HR deceleration that typically accompanies attention, Richards and his colleagues (e.g., Richards, 1997; Richards & Casey, 1991) have parsed infant looking into different phases of attention. *Orienting* (OR) is the latency of the HR deceleration after look onset and may be related to attentional engagement. *Sustained attention* (SA) is looking that is accompanied by a sustained HR deceleration and may reflect infants' active encoding or processing the stimulus. *Attention termination* (AT) is looking that continues after the decelerative phase has ended and may reflect infants' disengagement of attention. Prior work on the relation between these phases of attention and looking is also somewhat equivocal. Richards (1987, 1997) has suggested that SA represents active encoding; this logically implies that some parameter of SA (e.g., greater amount or depth of SA) should predict improved infant performance on cognitive tasks. In contrast, using HR-defined attention measures identical to those used by Richards (1997), Colombo, Richman, Shaddy, Greenhoot, and Maikranz (2001) recently found AT, and not SA, mediated infant performance; less AT predicted better recognition. A major difference of these two studies also lies with the nature of the stimuli used; Richards (1997) used dynamic stimuli, and Colombo et al. used static stimuli. As such, the conduct of a study measuring HR-defined phases of attention in the context of both types of stimuli across age would serve to address this issue.

This study used three stimulus conditions—static-mute (SM), dynamic-mute (DM), and dynamic-audio (DA)—similar to those used in past research (e.g., Burnham et al., 1988; Malcuit et al., 1991) to allow for direct comparison of the potential differences in infant attention measured at 4 and 6 months of age in an infant-controlled habituation paradigm while using Richard's (XXYEAR) model for parsing infant attention into HR-defined phases of OR, SA, and AT.

METHOD

Participants

Sixty-five infants (thirty-four 4-month-olds and thirty-one 6-month-olds) were recruited by mail and telephone from the Kansas City, XXSTATE, metropolitan area. Seven 4-month-olds were excluded from final analyses due to fussiness ($n = 6$) and prematurity (gestation < 37 weeks, $n = 1$). Six 6-month-olds were excluded from the final analyses due to fussiness or sleepiness ($n = 3$), prematurity ($n = 1$), equipment failure ($n = 1$), or parental interference ($n = 1$). The final sample of 52 healthy full-term infants included twenty-seven 4-month-olds ($M = 123.85$ days, $SD = 5.58$) and twenty-five 6-month-olds ($M = 185.88$ days, $SD = 4.43$). The sample was mostly Caucasian and middle class.

Apparatus

Testing arrangement. Infants were tested in a 2 m × 2 m darkened booth. All stimuli were shown on a 27-in. (0.7-m) television screen, positioned directly in front of the infant. Videotaped stimuli were played through two VCRs, one that controlled the habituation stimulus and another that controlled the novel stimulus. Infants were placed in a car seat located 0.9 m from the screen, such that stimuli subtended a visual angle of approximately 18° vertical by 16° horizontal. A video camera positioned just above the television screen recorded the infant's face while watching the stimuli. This video feed was monitored on a TV in a separate room by an observer who coded infants' looks online during each trial. A microcomputer timed looks for each trial, kept track of accumulated time, calculated the habituation criterion, and controlled the stimulus VCRs. The sessions were also videotaped for assessing reliability offline.

Measurement of HR. Infants' HR was measured with shielded Ag-AgCl electrodes placed on either side of the chest and grounded with an unshielded electrode just above the navel. The equipment and software (BioPac, Inc., Santa Barbara, CA) used to collect HR data was identical to that used by Colombo et al. (2001).

Stimuli

We used three stimulus categories described earlier: DA, DM, and SM. Within each category, two sets were used: reading or talking. In the reading set, a woman wearing a white T-shirt sat against a neutral background and read a passage from *One Fish, Two Fish, Red Fish, Blue Fish* by Dr. Seuss. In the talking set, the same woman (with a slightly different hairstyle but dressed and positioned as before) spoke in an infant-directed manner.

For both sets, the DA stimuli consisted of a 10-sec clip recorded in a continuous loop and presented with its accompanying soundtrack (60 dB at the infants' ears against a 40 dB ambient background). The DM stimuli were the DA clips with the soundtrack muted. The SM stimuli were still shots of the woman's smiling face taken from the dynamic clips.

Design

This design was a completely between-subject 3 (stimulus category: DA, DM, or SM) × 2 (age: 4 or 6 months) × 2 (stimulus set: talking or reading) × 2 (test condition: immediate or lagged) factorial design. The first three factors were discussed earlier.

The test condition factor represents the use of a partial-lag design (see Bertenthal, Haith, & Campos, 1983) that allows for assessment of recognition in all of the infants run through the protocol but also for tests of spontaneous regression effects following habituation. After infants attained the habituation criterion, four test trials were presented, two with the familiar (i.e., habituated-to) stimulus set (F) and two with the novel set (N) in alternating order (i.e., NFNF or FNFN; see Table 1). Half of the infants saw the novel set immediately after attaining the habituation criterion (i.e., immediate change condition), whereas the other half saw the familiar set for one more trial immediately after attaining the habituation criterion (lagged change condition).

Procedure

Infants were randomly assigned to conditions, taking care to assign approximately equal numbers of infants to each cell in the design. After attaching the HR electrodes, the infant was placed in a car seat located in the testing booth. The lights were then dimmed until completely off, and the observer started the session.

An infant-controlled habituation sequence (Horowitz, Paden, Bhana, & Self, 1972) was administered, followed by a sequential-trial test phase. During the sequence, the infant was shown the same stimulus repeatedly across successive trials

TABLE 1
Habituation Stimuli and Corresponding Novel and Familiar Test Stimuli

	Test Stimuli	
Habituation Stimuli	*Novel*	*Familiar*
SM		
Reading	SM talking	SM reading
Talking	SM reading	SM talking
DM		
Reading	DM talking	DM reading
Talking	DM reading	DM talking
DA		
Reading	DA talking	DA reading
Talking	DA reading	DA talking

Note. SM = static-mute; DM = dynamic-mute; DA = dynamic-audio.

until obtaining two consecutive looks equal to or less than 50% of the two previous longest looks. The number of trials each infant received thus varied based on his or her looking behavior (*M* = 6.02, *SD* = 3.95). Valid looks were defined as at least 1 sec in length, and looks were terminated by a look away of at least 1 sec. When looks were terminated, stimuli were removed for a 2-sec intertrial interval. Test trials immediately followed attainment of the habituation criterion.

Reliability observers (blind to test conditions) coded 25% of the sessions from videotaped records. The mean correlation for look durations coded by two observers was $r = .99$ (range = .95–1.00).

Data Reduction of HR

Infants' looking was parsed into categories of OR, SA, and AT (Richards & Casey, 1991, 1992). SA was defined as looking during which HR fell below a prestimulus baseline for at least five consecutive beats, OR was defined as that period of looking prior to the attainment of SA, and AT was defined as looking that continued after the infant's HR had returned to at least the prestimulus baseline level. Because OR and AT were defined relative to SA, only those habituation trials where SA occurred (*M* = 86.84%, *SD* = 17.52) were included in subsequent HR analyses. The intertrial interval prior to each trial served as the prestimulus baseline period because the median HR level varied significantly across trials, $F(2, 38) = 5.64$, $p < .01$. A more detailed explanation of the methods used to code and parse infants' HR files can be found in Colombo et al. (2001).

RESULTS

Look Duration

The first analysis tested for developmental and stimulus effects on infant look duration. Infants' average looking times across habituation trials were analyzed with a stimulus category (3: SM, DM, DA) × age (2: 4, 6 months) × stimulus set (2: talking, reading) analysis of variance (ANOVA).

This analysis yielded a significant main effect for stimulus category, $F(2, 40) = 11.15$, $p < .001$; infants looked less to the SM stimuli (*M* = 10.60, *SE* = 6.59) than to either the DM or DA stimuli (*M* = 34.06, *SE* = 6.59, $p < .05$, and *M* = 54.60, *SE* = 6.59, $p < .01$, respectively), which were marginally different from each other ($p = .075$). The age main effect was also significant, $F(1, 40) = 6.58$, $p < .05$, as 4-month-olds (*M* = 42.85, *SE* = 5.34) looked longer at the stimuli than 6-month-olds (*M* = 23.32, *SE* = 5.43). As expected, there were no significant results involving stimulus set, and so this factor was not entered in any subsequent analyses reported here.

TABLE 2
Means and Standard Deviations of Average Look Duration for the Different Age Groups and Stimulus Categories

	4 Months		*6 Months*	
Stimulus Category	*M*	*SD*	*M*	*SD*
SM	10.63[a]	5.81	10.87[a]	5.66
DM	53.36[a]	36.68	12.62[b]	13.60
DA	62.18[a]	37.28	46.66[b]	36.12

Note. SM = static-mute; DM = dynamic-mute; DA = dynamic-audio.
[a]$n = 9$. [b]$n = 8$.

None of the interactions attained statistical significance, even though the decline was evident and far more robust for the dynamic stimuli than for the static stimulus (see Table 2).

Discrimination Performance

Test for spontaneous regression. Paired-sample *t* tests were conducted on the second habituation criterion trial versus the first posthabituation test trial for both the immediate and lagged change groups. As expected, infants in the immediate condition showed significant recovery of looking time from the second criterion trial ($M = 8.64$, $SE = 2.28$) to the first test trial ($M = 18.10$, $SE = 4.74$), $t(26) = 3.05$, $p < .01$, whereas infants in the lagged condition did not (second criterion trial: $M = 9.55$, $SE = 1.82$; first test trial: $M = 13.81$, $SE = 2.94$), $t(24) = 1.55$, *ns*. These results ruled out spontaneous regression and allowed us to collapse subsequent analyses across test conditions.

Analysis of discrimination. The next analysis examined whether infants discriminated the stimulus sets. Looking times during the first familiar and first novel test trials were entered into a set (2: familiar vs. novel) × stimulus category × age mixed-model ANOVA.[1] All three main effects were significant.

The main effect for stimulus category, $F(2, 46) = 8.67$, $p = .001$, was caused by the DA stimuli ($M = 27.76$, $SE = 3.71$) eliciting significantly longer posthabituation looks than either the SM ($M = 6.96$, $SE = 3.60$) or DM ($M = 12.27$, $SE = 3.71$) conditions. The age main effect, $F(1, 46) = 8.51$, $p < .01$, mirrors the age effect seen during habituation, as 4-month-olds ($M = 21.84$, $SE = 2.94$) looked longer than 6-month-olds ($M = 9.48$, $SE = 3.06$). Finally, the main

[1]The second block of test trials was not included in any analyses because the second novel test trial was uncorrelated with the first novel test trial ($r = .21$, $p = .14$), thus suggesting that something other than the novelty of the stimulus was responsible for look duration during the second novel test trial.

effect for set, $F(1, 46) = 4.41$, $p < .05$, was produced by infants looking significantly longer at the novel set ($M = 19.13$, $SE = 3.46$) than to the familiar set ($M = 12.20$, $SE = 1.58$). No interaction terms were significant, implying equivalent recovery across ages and stimulus conditions.

Analyses of HR Measures

HR measures and look duration. As seen in Colombo et al. (2001), average looking time during habituation was unrelated to the average amount of looking spent in OR ($r = .06$, *ns*) but was strongly correlated with the average amount of looking spent in both SA and AT ($r = .92$ and .80, respectively, both $p < .001$). Given that OR was unrelated to look duration, it was omitted from analyses in the following section.

Individual differences in HR and discrimination performance. We next determined whether SA and AT were related to infants' performance on the test phase of the habituation task. To do this, infants were classified in terms of their recovery on the first presentation of the novel stimulus during the test phase. A novelty response score was computed by dividing the amount of time an infant spent looking during the first novel test trial by the amount of total time that infant spent looking during the first novel plus the first familiar test trials. We then calculated the minimum score that would still be considered significantly greater than chance (i.e., .50) at the one-tailed .05 level (0.548), that is, $t(51) = 1.68$, $SE = .029$. Infants were then respectively classified as recoverers (infants with novelty response score ≥ 0.548, $n = 30$) or nonrecoverers (infants with score < 0.548, $n = 22$). Average durations of SA and AT from the habituation phase were then entered into a phase (2: SA, AT) × age × stimulus category × recoverer (2: yes, no) mixed-model ANOVA. This yielded significant main effects for phase, $F(1, 40) = 9.62$, $p < .01$; age, $F(1, 40) = 6.79$, $p < .05$; and stimulus category, $F(2, 40) = 7.74$, $p = .001$, and a significant Phase × Stimulus Category interaction, $F(2, 40) = 10.51$, $p < .001$. All of these terms were qualified by a significant four-way interaction, $F(2, 40) = 3.87$, $p < .05$. To render this interaction more interpretable, we decomposed it by conducting Stimulus Category × Age × Recoverer ANOVAs separately for average SA and AT.

The analysis of AT yielded significant main effects for stimulus category, $F(2, 40) = 3.30$, $p < .05$, and age, $F(1, 40) = 5.39$, $p < .05$, and a significant Stimulus Category × Age interaction, $F(2, 40) = 3.45$, $p < .05$. These terms were due to differences in look duration previously documented for age and stimulus conditions, given that look duration was highly correlated with AT; as such, they are artifactual. The key point here was that no significant terms involving recoverer emerged (see Figure 1). AT therefore did not differentiate between infants who discriminated the novel stimulus set and those who did not.

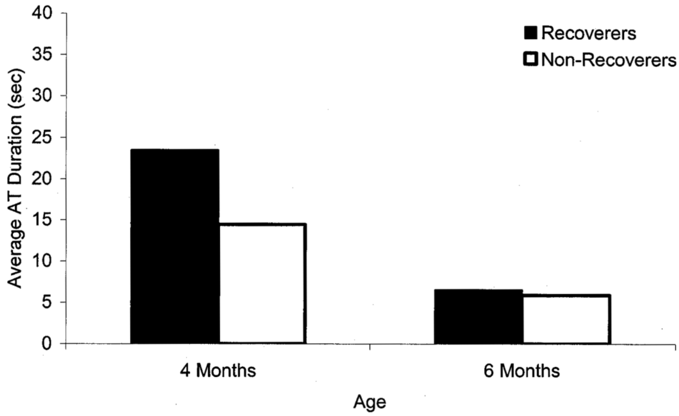

FIGURE 1 Average duration of attention termination (AT) as a function of age and recoverer classification.

The SA analysis also revealed artifactual significant effects for age, $F(1, 40) = 5.26$, $p < .05$, and stimulus category, $F(2, 40) = 15.16$, $p < .001$. However, a significant Age × Recoverer interaction, $F(1, 40) = 4.54$, $p < .05$, emerged (see Figure 2). Four-month-olds who recovered to the novel stimulus set ($M = 34.09$, $SE = 4.13$) spent twice as much time in SA than those who did not ($M = 16.33$, $SE = 4.62$).[2] The 6-month-olds differed little across recovery group in the amount of time spent in SA (recoverers: $M = 13.21$, $SE = 4.46$; nonrecoverers: $M = 15.92$, $SE = 5.33$).

DISCUSSION

The central focus of the study was to determine whether a decline in look duration was demonstrable across this age range for dynamic as well as static stimuli. The age-related decline in look duration was not observed specifically in the static condition in this study, but this phenomenon has been widely observed and replicated elsewhere. The current data are clearly in accord with those studies finding the decline for dynamic stimulus categories; a robust and reliable decline in look duration was observed for all dynamic conditions here.

Another goal of this study was to address what attentional mechanisms mediate individual differences in infant cognitive performance. This was accomplished by

[2]Because SA has been shown to correlate strongly with look duration, it is important to note that the effect observed in 4-month-olds with respect to SA and recovery was independent of individual differences in look duration. If a stimulus category (3) × recovery (2) ANOVA is run for the 4-month-old group with average look duration entered as a covariate, the main effect for recovery remains significant, $F(1, 20) = 5.95$, $p < .05$.

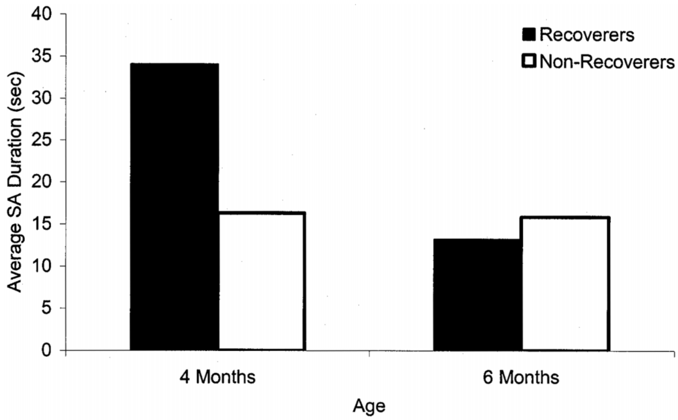

FIGURE 2 Average duration of sustained attention (SA) as a function of age and recoverer classification.

examining the relation between HR-defined phases of attention and infant discrimination of the stimulus sets. We hypothesized that the static or dynamic stimulus factor might be differentially sensitive to different mechanisms underlying attention (i.e., AT might be negatively related to discrimination of static stimuli and SA positively related to discrimination of dynamic stimuli), but we found no evidence in support of this. Instead, in 4-month-olds, SA mediated discrimination of all stimulus types; 4-month-olds who recognized the familiar stimulus had greater amounts of SA than those that did not recognize the familiar stimulus, regardless of stimulus category. These findings raise two questions.

The first question concerns why AT (rather than SA) successfully predicted recognition in Colombo et al. (2001). Colombo et al. observed that AT predicted paired-comparison recognition performance under conditions involving a limited amount of familiarization (i.e., approximating the format of a speeded cognitive task). The study reported here used an infant-controlled habituation protocol in which infants look ad libitum prior to the administration of the test phase. It seems reasonable to posit that AT might interfere with infants' ability to encode the stimulus completely more readily under conditions where infants have only a limited amount of time to process stimuli.

The second question concerns why the relation between SA and recovery was observed only for 4-month-olds. It is possible that, by 6 months of age, infants are all capable of processing visual information with adequate speed or facility, and that the mere amount of time spent in SA will not be an advantageous predictor of cognitive performance in these paradigms. Thus, although the quantity of encoding might not mediate individual differences in recognition memory performance at 6 months, it is possible that the quality of encoding does. This issue will be resolved through future work on the topic.

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