

## Heart Rate-Defined Phases of Attention, Look Duration, and Infant Performance in the Paired-Comparison Paradigm

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Four-month-old infants ( $N = 68$ ) were tested in a paired-comparison familiarization–novelty recognition task in which the length of choice trials was systematically manipulated. Peak look duration during pretest and familiarization periods significantly predicted a dichotomous measure of recognition performance, but recognition was unaffected by choice-trial length. Heart rate (HR) was simultaneously assessed during the task, and the amount of time infants spent in various HR-defined phases of attention was assessed. Longer durations of looking during pretest and familiarization were significantly associated with more time spent in both sustained attention (SA) and attention termination (AT). Of these two variables, only individual differences in AT accounted for significant variance in recognition memory performance. A final analysis addressed the possibility that individual differences in AT mediated the relation between look duration and recognition performance. These findings provide support for the hypothesis that individual differences in the disengagement of attention underlie the relation between look duration and cognitive performance in early to midinfancy.

### INTRODUCTION

Over the past 30 years, research on infant attention has relied on selective-looking and habituation paradigms. Within the context of these procedures, a common and replicable finding (Colombo & Mitchell, 1990; Mayes & Kessen, 1989) is that the length of infants' duration of looking to static, two-dimensional stimuli declines from about 8 to 10 weeks of age to some point during the second half of the first year (see Colombo, Harlan, & Mitchell, 1999).

The decline in look duration has been interpreted in various ways, but the predominant hypothesis involves changes in the rapidity with which infants encode visual information. This hypothesis has been supported by both cross-age and within-age data. For example, in paired-comparison familiarization–novelty tasks, younger infants (who look for longer durations than older infants) require more study time ("familiarization") than older infants to show recognition of visual stimuli (e.g., Fagan & Shepard, 1986). This finding has been reported to hold within ages as well; longer looking infants require more familiarization time to show recognition than their shorter looking counterparts (e.g., Colombo, Mitchell, Coldren, & Freese, 1991; Jankowski & Rose, 1997). As such, under conditions in which familiarization is fixed and marginally sufficient for recognition, look duration and recognition performance have been observed to be negatively correlated (Colombo, Mitchell, & Horowitz, 1988).

A recent addition to the hypotheses concerning individual and developmental differences in look duration in infancy comes from the developmental cog-

nitive neuroscience approach (Colombo, 1995; Hood, 1995; Johnson, 1997; Richards, 1998). In this approach, infant attention has been conceptualized in terms of the components of adult visual attention (e.g., Posner, 1980) and the brain systems that mediate them (Posner, 1981; Posner & Petersen, 1990; Posner, Petersen, Fox, & Raichle, 1988), and validated through convergent behavioral and biological/psychophysiological measures (e.g., Richards, 1998). From this point of view, prolonged look duration has been characterized as difficulty with the disengagement of fixation (Colombo, 1995; Hood, 1995; Johnson, 1990). There are two competing accounts (Hood, 1995; Johnson, 1990) of why young infants might experience difficulty in disengagement of fixation from a visual stimulus. Johnson's model holds that input derived from fixating the visual stimulus produces diffuse cortical activity; in turn, this activity inhibits the superior collicular pathway responsible for triggering an eye movement to a stimulus appearing in the periphery. As a result, fixation becomes locked onto the stimulus being inspected. Hood, on the other hand, attributes difficulty in infant disengagement to maturation of the parietal lobe, which is an area associated with attentional disengagement in adults (Posner & Petersen, 1990).

The process of attentional disengagement and developmental lags in the emergence of this ability in infancy has been linked theoretically to the manner in which infants attend to particular elements or features of displays in the visual field (Colombo, 1995). Indeed, very young infants (Bronson, 1982; Salapatek,

1968, 1975; Salapatek & Kessen, 1966), and older infants who engage in "less-mature" patterns of prolonged looking (Bronson, 1990, 1991, 1994, 1997; Jankowski & Rose, 1997) tend to show attentional patterns that have been characterized as "perseverative" (Krinsky-McHale & Hainline, 1996) or being "stuck" (Hood, 1995) on visual elements within stimulus displays. Furthermore, 3- to 4-month-old infants with patterns of prolonged looking engage in a sequence of visual encoding that is consistent with an emphasis on the processing of "local" visual elements (Colombo, Freese-man, Coldren, & Frick, 1995; Colombo, Frick, Ryther, & Gifford, 1996; Freese-man, Colombo, & Coldren, 1993; Stoecker, Colombo, Frick, & Allen, 1998). Perhaps the best evidence in favor of this hypothesis comes from Frick, Colombo, and Saxon (1999), who reported on the performance of 3- and 4-month-old infants in a gap/overlap paradigm. Frick et al. found that duration of looking in 3- and 4-month-old infants was positively and significantly correlated with latencies to make an eye movement toward a peripheral target under conditions in which a central target remained illuminated at midline. In such an "overlap" condition, attentional disengagement is necessary prior to making such a shift toward the periphery. Such correlations, however, were nonexistent under conditions in which the central target was withdrawn before the presentation of the peripheral target. In this "gap" condition, attentional disengagement is not necessary prior to making such an eye movement.

The disengagement hypothesis of look duration offers a prediction about long-looking infants' performance in paired-comparison familiarization–novelty tasks that has not yet been tested. In such tasks, recognition performance is assessed in paired-comparison "choice" trials in which brief amounts of looking are accumulated to the novel and familiar stimuli. If long-looking infants have difficulty disengaging visual attention, it may be that such a testing protocol puts these infants at a disadvantage for showing novelty preferences (i.e., the fundamental measure of recognition from this paradigm). Thus, one aim of the current study was to evaluate the effect of increasing the length of these choice trials (which, for 3- and 4-month-old infants, are typically 5–10 s in length). By increasing the length of choice trials, and thereby allowing more time for infants to make their choices, one might eliminate the deficit on such tasks that has often been reported for long-looking infants.

The current study, however, also addressed these hypotheses by the inclusion of heart rate (HR) measures taken while infants attended to visual stimuli. Richards and Casey (1992) have posited that simultaneous measurement of HR during infant looking to

visual displays can allow for a parsing of attention into three different "phases" of attention: orienting (OR), sustained attention (SA), and attention termination (AT). These three types of attention presumably reflect different types of information processing. Richards and Casey indicate that SA reflects a voluntary mode of attention, similar to the functions identified for the anterior system (Posner & Petersen, 1990). However, AT is postulated to reflect a period during which looking continues, but the infant is no longer engaged in processing information. In this way, AT may most closely reflect the disengagement of attention (Richards & Casey, 1992) that Posner and Cohen (1982) have identified with the posterior attention system. In the current study, we measured infant HR during the paired-comparison task and parsed attention into the three phases of attention identified by Richards (1987; Richards & Casey, 1992). Our aim was to determine the degree to which look duration and these three phases interrelate with respect to recognition performance. If, in fact, the individual differences in infant look duration that relate to recognition are linked with some aspect of active visual encoding, then we might expect that look duration would be associated with SA, and that perhaps SA would mediate the relation between look duration and recognition performance. If, on the other hand, individual differences in infant look duration and recognition at this age reflect disengagement of attention, then we would expect that look duration would be associated with AT, and that perhaps AT would mediate the look duration–recognition performance relation.

## METHOD

### Participants

A total of 113 four-month-old infants (*range* = 119–126 days) were recruited by mail and telephone from the greater Kansas City metropolitan area. Twenty-five infants were excluded from final analyses for protocol violation or because of exclusionary criteria: fussiness ( $n = 19$ ), experimenter error ( $n = 1$ ), equipment failure ( $n = 2$ ), gestation length less than 37 weeks ( $n = 2$ ), and parental interference ( $n = 1$ ). Thus, 88 infants were available for analyses of performance on the pretest and familiarization periods of the study. An additional 16 infants were excluded from analyses of recognition performance due to failure to compare the paired stimuli on the choice trials (see Procedure section below). After this exclusion, a total of 72 infants remained who had successfully completed the pretest, familiarization, and paired-comparison periods of the protocol. However, of these 72 infants,

4 had incomplete HR data because of either excessive movement or loss of contact between the electrodes and their body at some point during the session. The exclusion of these final 4 infants thus left a sample of 68 infants who had both complete behavioral and psychophysiological data for the entire session.

### Apparatus and Stimuli

*Testing set-up.* Infants were tested in a 2 m × 2 m booth, painted black on all walls and ceiling. In the wall facing the infant was a 1.0 m × .7 m translucent rear-projection screen on which all visual stimuli were presented. Infants were placed in a car seat .8 m from the screen. Stimuli were presented with Kodak Ektagraphic carousel slide projectors. At the base of the screen, a Panasonic video camera was positioned to record the infant's face while watching the stimuli. The video feed from this camera was sent to a VCR and TV monitor so that an observer could code infants' looks during each of the periods.

Observers watched the session on the monitor and coded looks online by pressing buttons that were interfaced with a microcomputer that timed looks, kept track of accumulated time, and controlled the slide projectors. This computer also sent signals to the HR data acquisition package interface (see below). A second observer coded sessions from the videotape to obtain reliability for the critical dependent measures.

*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 electrocardiogram (EKG) was digitized through the use of a data acquisition interface and second computer running software from a commercial data acquisition package (BioPac, Inc., Santa Barbara, CA) configured for psychophysiological recording. The EKG was sampled at a rate of 250 Hz. The data acquisition interface also received input from the timing computer, so that the HR record could be synchronized with stimulus events and the coding of fixations.

*Stimuli.* Three stimuli were used in the study. A color photograph of a female face was used for the pretest. For the recognition task, a pair of stimuli comprised of 22 dots placed in different configurations (a concentric square pattern versus a filled diamond pattern) was employed. This pair was used in Colombo et al. (1991). In that study, 20 s of familiarization time was demonstrated to be barely sufficient for recognition.

### Procedure

*Baseline.* After administration of informed consent to the accompanying parent(s), infants were carried

into the testing booth, and placed in a car seat in front of the rear-projection screen. After obtaining a clear EKG signal, the room light was dimmed gradually until completely off, and the infant sat in the darkened room with no stimulus while baseline HR was collected. The length of the baseline period varied somewhat, but its average was 30.4 s ( $SE = 2.0$  s), and the length of the period was uncorrelated with infant HR during the period.

*Pretest.* Prior to the beginning of the paired-comparison recognition task, infants were shown the slide of the female face at midline. The face subtended a visual angle of 20° horizontal × 16° vertical. The face was presented until the infant accumulated 20 s of looking. Looks were coded online by an observer watching the session from the video feed; the main measure was the duration of the peak look during the session. A second observer rescored 24% of the sessions from the videotapes of the live sessions; reliability for the duration of peak look during the pretest was .95.

*Familiarization.* The period between pretest and familiarization allowed for another measurement of baseline HR. The length of this interval varied slightly, but was, on average, 23.5 s ( $SE = .5$  s); again, its length was uncorrelated with the level of the resting HR. After this interval, the familiarization period of the recognition task was begun. Infants were shown one of the two dot-matrix stimuli used in Colombo et al. (1991) at midline; the stimulus serving as familiar was balanced across subjects. As with the pretest stimulus, the familiarization stimulus (visual angle of 16° horizontal × 20° vertical) remained on the screen until infants accumulated 20 s of looking toward it. Looks were coded online, as specified during the pretest, and again, the primary measure was the duration of the peak look. The reliability for duration of peak look during familiarization was .99.

*Choice trials.* The choice trial period began 650 ms after the end of the familiarization period. In this period, the familiarized stimulus was simultaneously paired with the other (novel) stimulus. Stimuli were the same size as during the familiarization period, except that they were shown 10° to the left and right of midline (i.e., 20° apart). The length of the choice trials was systematically varied between subjects at either 5 s or 15 s of accumulated looking. During this period, both stimuli remained illuminated until the prescribed amount of looking had been accumulated. Once this level of looking was attained, the stimuli were turned off for 1 s and then reilluminated with the lateral positions reversed (relative to the first choice trial). The prescribed amount of looking was again accumulated for the second choice trial. The assignment of the lateral position of the two stimuli

was randomized across subjects, and novelty preference was calculated by dividing the total time looking toward the novel stimulus across both trials by the total time of the two choice trials. The reliability of the online coding of novelty preference was .99.

During the choice trials, 16 infants did not actively compare the two stimuli, and were, therefore, excluded from analyses of recognition performance. Of these infants, 12 looked toward only one lateral position (i.e., they looked to either the left or the right target across both choice trials; see Freese et al., 1993). Such *complete lateral bias* produces artifactual novelty preferences at exactly chance levels (50%). Another 4 infants did not actively shift fixations between the paired targets presented on choice trials, but rather looked at one lateral position on the first trial, and the other lateral position on the next trial. This *failure to shift* results in novelty preferences that are either exactly 0% or exactly 100%. These values are of suspect validity and add variability to the distribution. Of interest is the fact that 15 of these 16 exclusions occurred in the 5-s choice-trial condition. Indeed, this distribution of exclusion as a function of choice-trial length was statistically significant,  $\chi^2(2) = 15.1$ ,  $p < .001$ . In keeping with the original hypothesis of the study, this supports the notion that brief choice-trial lengths interfere with some infants' opportunity to engage in active comparison of the paired stimuli during the test sessions.

## DATA REDUCTION AND ANALYTIC STRATEGIES

### HR-Defined Phases of Attention

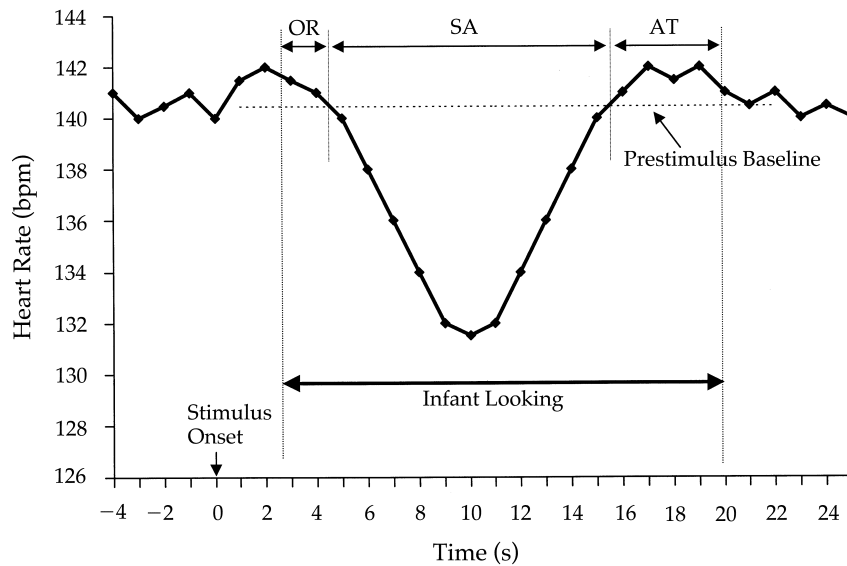
*Reduction and handling of HR data.* Infants' HR was converted into a data file using BioPac, Inc. software that identified and stored the time code of the R waves from the digitized EKG. The time codes from stimulus events (slide onsets and offsets) and infant behaviors (look onsets and offsets) were then interspersed among the R-wave time codes to provide a complete sequential record of the infant's session. The sequential file was then analyzed on a beat-by-beat basis with custom software that parsed infants' looking into categories of OR, SA, and AT based on Richards' (1985; Casey & Richards, 1988) framework. Richards (e.g., 1997) defines SA as looking accompanied by at least five consecutive beats below the median HR observed in a prestimulus period. OR was defined as that period of looking prior to the attainment of SA, and AT was defined as looking that continues after SA, but during which HR has returned to at least the prestimulus median baseline level. Figure 1 pre-

sents an example of how these phases were coded within the context of a single look.

*Calculation of HR-defined attentional phases.* The pre-session baseline served as the prestimulus period for the pretest period, the interval between pretest and familiarization served as the prestimulus period for the familiarization period, and the brief period between familiarization and choice-trial periods served as the prestimulus period for choice trials. Median HR varied significantly across these periods,  $F(2, 61) = 44.77$ ,  $p < .001$ , but this was attributable to significant differences between mean HR during the pre-session baseline and the other two periods; the latter two values did not vary significantly from one another. Infants' mean HR was significantly correlated across all three of these prestimulus periods,  $p < .001$ . Baseline median correlated .85 with the pretest/familiarization median, baseline median correlated .62 with the familiarization/choice-trial median, and pretest/familiarization median correlated .80 with the familiarization/choice-trial median. Means for HR during prestimulus baseline, OR, SA, and AT are presented in Table 1.

In coding for SA, varying numbers of looks were encountered in which no SA could be coded. Because attention cannot be parsed without the attainment of SA (i.e., logically, neither OR nor AT are coded unless SA occurs), if SA was not observed within a particular look, it was excluded from the analyses. After such exclusions, the amount of time observed in each of the phases within the pretest, familiarization, and choice-trial protocol periods was summed to create the variables used in the analyses.

*Recognition/discrimination performance measure.* Novelty preference (the percentage of time that infants fixate the novel target during the choice trials) is the typical measure of infant recognition in the paired-comparison paradigm. In the adult literature, both discrimination and recognition performance are generally considered to be dichotomous (i.e., yes/no), all-or-none phenomenon. Generally, however, novelty preference is analyzed as a continuous measure (its value ranges from 0–100%), despite the fact that an a priori chance level (i.e., 50%) does exist. The implication of analyzing novelty preference as a continuous variable is that higher scores are presumed to reflect better discrimination or recognition. However, after demonstration that infants' scores exceed chance, there is no empirical evidence to directly support the notion that a novelty preference score of, for example, 65% reflects performance that is superior to, for example, 55%. There is precedence for the use of this 55% criterion in the infant perception literature; categorical cutoffs like this have been validated in prediction



**Figure 1** Schematic representation of how orienting (OR), sustained attention (SA), and attention termination (AT) were coded within a single look. Stimulus onset occurred at the point designated on the x axis as 0, the infant began looking at approximately 2.75 s and ended looking at approximately 20 s. The heavy black line shows infant heart rate (HR), and the dotted horizontal line represents the baseline HR level derived from a prestimulus period. SA was coded if the infant showed at least five consecutive beats below baseline level during a look. The period between the start of the look and the onset of SA was coded as OR, and the period after HR returned to baseline, but while the infant was still looking was coded as AT.

studies (Fagan, Singer, Montie, & Shepard, 1986; Rose, Feldman, Wallace, & McCarton, 1989) and have been reported in experimental work (e.g., Frick & Colombo, 1996).

In this study infants' recognition performance was analyzed as a dichotomous variable instead of subjecting the continuous measure to parametric analyses. The dichotomous measure was constructed by dividing novelty preference at a cut-off point of 55%. Infants showing a novelty preference at 55% or above were considered to have successfully recognized the familiarized stimulus, whereas those below 55% were considered to have not done so. The value of 55% was chosen based on (1) our past experience with this measure and paradigm, (2) other studies that have used this cutoff (e.g., Fagan et al., 1986), and (3) the

fact that this value represented the mean overall performance of the sample (see Results below).

## RESULTS

### Infants' Looking on Pretest and Familiarization Periods

In keeping with numerous other reports on the consistency of look duration, peak looks were positively and significantly correlated across these two periods,  $r(88) = .34, p = .001$ . If only infants who successfully completed *all* periods of the behavioral protocol were considered ( $n = 72$ ), the correlation increased to  $r(72) = .41, p < .001$ .

Infants' peak look during the pretest (with the female face) averaged 9.8 s ( $SD = 5.2$  s). The peak look

**Table 1** Mean Infants' Heart Rate during Prestimulus Periods and Attentional Phases across All Protocol Periods

Protocol Period	Prestimulus	Orienting	Sustained Attention	Attention Termination
Pretest	147.9 (11.1)	153.2 (10.7)	142.0 (11.9)	150.3 (11.4)
Familiarization	154.9 (11.3)	157.0 (13.4)	145.8 (11.7)	154.6 (10.2)
Choice-Trial 1	154.1 (15.9)	151.7 (14.7)	148.2 (13.8)	156.1 (14.3)
Choice-Trial 2	—	151.1 (15.4)	143.1 (13.8)	148.8 (11.3)

*Note:* Values in parentheses are standard deviations. Heart rate is given in beats per minute.

during familiarization was 11.7 s ( $SD = 5.5$  s). These look durations were significantly different from one another,  $t(87) = 2.89, p < .01$ , but because stimulus order was not varied in the protocol, it was unclear whether this was attributable to a stimulus or order effect. Infants who subsequently showed either lateral bias or failure to shift during choice-trials tended to have slightly longer peak looks (averaged across pretest and familiarization) than infants who successfully completed the choice-trial period (respective means were 11.6 s, 11.4 s, and 10.5 s). However, these differences did not approach statistical significance.

#### Analyses of Choice-Trial Duration and Looking Profile on Recognition

Overall, infants showed recognition for the familiarized target. The mean novelty preference across all conditions and individual difference groups was 55.2% ( $SD = 13.7$ ). This value was significantly greater than chance (50%),  $t(71) = 3.21, p = .002$ . Having established that the overall normative response for infants in the current study was, in fact, a novelty preference, infants' responses were dichotomized as yes or no outcomes, using a novelty preference cutoff of 55% (see above). That is, infants with novelty preferences at or above 55% were classified as having recognized the familiarized stimulus, whereas those below 55% were considered to have not recognized the familiarized stimulus. Thirty-nine of the 72 infants (54%) who completed the choice-trial test sessions showed novelty preferences at or above 55%.

Following the choice of this cutoff for dichotomizing discrimination–recognition performance, the variable was entered into a binary logistic regression analysis. The logistic regression is similar to multiple regression, except that the criterion variable is dichotomous rather than continuous. The explanatory variables may be either categorical or continuous. As such, infant recognition could be predicted as either a function of the categorical choice-trial length variable, or as a function of the characteristic look duration observed in infants across both the pretest and familiarization periods (i.e., the mean of the peak looks from pretest and familiarization). Furthermore, as with multiple regression, it is possible to examine the extent to which interactions between the explanatory variables account for the outcome measure.

To test the hypothesis that recognition performance might be affected by choice-trial length and the mean peak look duration from pretest and familiarization, a logistic model that included both these main effects and an interaction term between the two was tested first. The test of the interaction term, how-

ever, was not significant, Wald  $\chi^2(1) = .11, ns$ , and so the interaction term was removed and a model including only the main effects was tested.

The main-effects model (see Table 2) fit adequately, goodness-of-fit  $\chi^2(8) = 6.78, ns$ , and yielded an overall score statistic of  $\chi^2(2) = 5.50, p = .06$ . Examination of the parameter estimates showed that in keeping with past findings (Colombo et al., 1991; Jankowsky & Rose, 1997), mean peak look was significantly and negatively related to the likelihood of infants' successful recognition on the task. That is, shorter looking infants were more likely to show recognition than were longer looking infants. At the same time, choice trial length did not account for variation in infant task performance.

#### HR-Defined Phases of Attention

*Descriptive statistics and analyses.* A Phase (3: OR, SA, AT)  $\times$  Protocol Period (2: pretest, familiarization) within-subjects ANOVA was conducted on the time infants spent in each phase of attention. A Phase (3)  $\times$  Choice-Trial Length (2: 5 versus 15 s) mixed-design ANOVA was performed on the same variable observed during choice trials. Table 3 shows the means and standard errors for each of these analyses.

The Phase  $\times$  Protocol Period ANOVA yielded a significant main effect for Phase,  $F(2, 41) = 79.07, p < .001$ , and a significant two-way interaction,  $F(2, 41) = 9.08, p = .001$ . The amount of OR did not vary across pretest and familiarization, but there was less SA,  $p < .01$ , and more AT,  $p < .01$ , during the pretest, relative to familiarization.

The analysis for choice trial (again, see Table 3) yielded a significant main effect for phase,  $F(2, 28) = 30.84, p < .001$ , and a significant two-way Phase  $\times$  Choice Trial Length interaction,  $F(2, 28) = 3.78, p < .05$ . The interaction was attributable to significantly more SA,  $p < .001$ , and AT,  $p = .05$ , being observed in the 15-s choice trials than in the 5-s trials, whereas the amount of OR did not change.

*Summary.* Across all three protocol periods, the predominant attentional phase observed was SA. There was more SA and less AT during familiariza-

**Table 2** Main Effects Binary Regression Model: Prediction of Likelihood of Infant Success on Recognition Task from Choice-Trial Length and Look Duration

Variable	B	SE	Wald $\chi^2(1)$
Choice-trial length	-.138	.511	.07
Peak look duration	-.128	.057	5.04*

\* $p < .05$ .

**Table 3 Mean Time Spent in Attentional Phases as a Function of Protocol Period**

Protocol Period	Attentional Phase	Mean Time (s)	(SE)	
Pretest	OR	2.55	(.54)	
	SA	8.89	(.71)	
	AT	3.40	(.63)	
Familiarization	OR	1.42	(.40)	
	SA	13.00	(.96)	
	AT	1.40	(.37)	
Choice trials	5-s trials	OR	.32	(.92)
		SA	7.15	(1.91)
		AT	.09	(1.30)
	15-s trials	OR	2.16	(.55)
		SA	15.44	(1.12)
		AT	3.16	(.77)

Note: The time spent in attentional phases does not sum to the total time of accumulated looking in the protocol period, because no attentional phases were coded for looks in which SA did not occur. Values in parentheses are standard errors. OR = orienting; SA = sustained attention; AT = attention termination.

tion relative to pretest, but again, because the order of stimulus presentation was not varied, it is unclear whether this was a stimulus (e.g., social versus non-social) effect or order effect. In addition, lengthening the choice trials also increased the amount of SA and AT observed; increasing choice trials from 5 s to 15 s more than doubled the amount of SA, and increased AT from near 0 to about 3.5 s.

#### Concordance of Attentional Phases across Protocol Periods

We next attempted to determine whether individual differences in the three phases (OR, SA, and AT) were correlated across the pretest and familiarization periods of the experimental protocol. Table 4 shows these zero-order correlations. Only AT was significantly correlated from pretest to familiarization.

#### Duration of Looking on Pretest and Familiarization and HR-Defined Phases of Attention

The next series of analyses sought to determine whether the behavioral measure of look duration (i.e., duration of peak look during the pretest and familiarization periods) bore any relation to the HR-defined phases of attention.

*Pretest.* Correlations between peak look to the face during the pretest and amount of time spent in OR, SA, and AT are shown in Table 5. OR was unrelated to

**Table 4 Intercorrelations among Measures of Orienting (OR), Sustained Attention (SA), and Attention Termination (AT) across Pretest and Familiarization**

Attentional Phase	<i>r</i>
OR	-.04
SA	-.01
AT	.52***

Note: Statistical outliers were identified (one for OR, two for AT) using standardized residuals and excluded from correlations shown in this table.

\*\*\*  $p < .001$ .

look duration, but look duration was generally positively correlated with both SA and AT. Thus, long looking could be characterized as reflecting more sustained attention (i.e., information processing), but also more attention termination (i.e., continuation of looking after information processing has terminated).

*Familiarization.* Correlations between peak look to the stimuli presented during familiarization and the amount of time spent in OR, SA, and AT are shown in Table 5. Here, the same pattern of results emerged as for the pretest. Look duration was unrelated to OR, but significantly and positively correlated with SA and AT.

*Overall correlations for aggregate measures.* To obtain a more reliable estimate of both look duration and overall propensity for the various phases of attention, the peak look across pretest and familiarization were averaged, and the amount of time accumulated in OR, SA, and AT was totaled across these same two protocol periods. The correlations between this aggregate measure of look duration and time in the various attentional phases are presented in Table 5. Again, look duration significantly and positively correlated with SA and AT, but not with OR.

*Summary.* In summary, then, longer look durations were consistently related to more time spent in SA and

**Table 5 Correlations between Peak Look Duration from Pretest and Familiarization with Amount of Time Spent in Each Attentional Phase**

Attentional Phase	Pretest	Familiarization	Aggregate Measures <sup>a</sup>
OR	-.06	-.05	.11
SA	.26	.45***	.45***
AT	.63***	.36**	.58***

Note: OR = orienting; SA = sustained attention; AT = attention termination.

<sup>a</sup> Aggregate Measures refers to the totals of OR, SA, and AT across pretest and familiarization as correlated with mean peak look across pretest and familiarization.

\*\*  $p < .01$ ; \*\*\*  $p < .001$ .

AT, both within protocol periods and when measures were aggregated across protocol periods. OR was unrelated to look duration under any examination.

#### HR-Defined Phases and Recognition Performance

*SA, AT, and recognition.* The set of analyses presented here concerned the relation between the HR-defined phases of attention and infants' performance on the recognition memory problem. Previous analyses had established that the continuous measure of look duration calculated from pretest and familiarization significantly predicted the dichotomous measure of infants' recognition of the familiarized stimulus. Previous analyses also demonstrated that look duration was significantly correlated with the amount of SA and AT, with long looking associated with more time spent in each of these two phases. In this final set of analyses, we sought to determine whether the amount of time spent in those HR-defined phases shown to be associated with look duration (i.e., SA, AT, or both) significantly predicted recognition.

As with the earlier analysis of recognition, a binary logistic regression was used to predict the dichotomous recognition measure, with SA and AT (amount of time in each totaled across pretest and familiarization) as the explanatory variables. As before, a preliminary model was fit including an SA  $\times$  AT interaction, but once again the interaction was not significant, Wald  $\chi^2(1) = .23$ , *ns*, indicating that a model including only main effects for SA and AT was adequate and preferable. The main-effects model fit adequately, GIF  $\chi^2(7) = 13.5$ , *ns*, and yielded a significant overall summary score,  $\chi^2(2) = 8.80$ ,  $p = .01$ . A regression including these main effects (see Table 6) indicated that the amount of time spent in SA did not significantly contribute toward the prediction of the likelihood of infant recognition. The amount of time spent in AT, however, was significantly related to the likelihood of recognition. The direction of the relation was negative; thus, the more time the infant spent in AT, the lower the likelihood of success at the recognition task.

**Table 6** Prediction of Likelihood of Infant Success on Recognition Task from Amounts of Sustained Attention (SA) and Attention Termination (AT) during Pretest and Familiarization

Variable	B	SE	Wald $\chi^2(1)$
SA	-.040	.031	1.65
AT	-.162	.074	4.85*

Note: Model  $\chi^2(2) = 8.80$ ,  $p = .012$ .

\* $p < .05$ .

It may be of interest to note the outcome of similar analyses conducted using an AT/SA ratio. These results echo the main analyses reported in this section. The AT/SA ratio ( $M = .24$ ,  $SD = .43$ ) was positively correlated with look duration,  $r(66) = .39$ ,  $p < .001$ ; thus, longer looking was characterized by more AT, relative to SA. A logistic regression model using the ratio to predict recognition success was significant,  $\chi^2(1) = 3.91$ ,  $p < .05$ , such that lower ratios (i.e., less AT relative to SA) predicted higher probabilities of recognition.

*Look duration, AT, and recognition.* The findings thus far indicated that (1) look duration significantly predicted the likelihood of recognition performance, and (2) SA and AT significantly varied with look duration, but (3) only AT significantly predicted recognition. Prior research (e.g., Frick et al., 1999) suggests that disengagement of attention may mediate individual differences in look duration during this point of infancy. It seems possible, then, that disengagement (here, operationalized as AT) might mediate the relation between look duration and recognition performance observed in this and other studies. This was accomplished with a set of two binary logistic regressions using an approach suggested by Baron and Kenny (1986). In this approach, one variable mediates the relation between an independent variable (IV) and a dependent variable (DV) if the following conditions are met: (1) the mediator is related to the IV; (2) the IV predicts the DV when considered independent of the mediator, and (3) when the mediator and the IV are jointly considered in the model, the mediator should predict the DV, and the predictive value of the IV should be reduced to the level of nonsignificance.

Having established that look duration covaries with AT (see Table 5 above), we next entered look duration alone as a predictor of infant recognition. As expected, this model fit well, GIF  $\chi^2(8) = 10.5$ , *ns*, and yielded a significant overall score statistic,  $\chi^2(1) = 5.42$ ,  $p = .02$ . Examination of the parameter estimates indicated that look duration showed significant prediction of the likelihood of infant recognition (see Table 7, Step 1). In the final analysis step, a logistic regression that included both look duration and the mediator (here, disengagement operationalized as AT) was conducted. This model also fit well, GIF  $\chi^2(7) = 4.14$ , *ns*, and the score statistic,  $\chi^2(2) = 7.30$ ,  $p = .03$ , indicated that the overall model was significant. As Table 7 indicates, look duration was no longer a significant predictor of recognition, because the Wald  $\chi^2(1)$  for look duration was reduced from 5.01 to .20, and the parameter estimate for look duration dropped to near 0. A comparison of the parameter estimates at this final step showed that AT was a better predictor of recognition in this model. The predictive effect for

**Table 7 Binary Logistic Models Testing the Status of Attention Termination (AT) as Mediator of Relation between Look Duration and Recognition Performance**

Variable	B	SE	Wald $\chi^2(1)$
Step 1: Regression of look duration on recognition performance <sup>a</sup>			
Look duration	-.126	.056	5.02*
Step 2: Entry of mediator (AT) into regression <sup>b</sup>			
Look duration	-.031	.069	0.20
AT	-.150	.088	2.92 <sup>+</sup>

<sup>a</sup> Model  $\chi^2(1) = 5.42; p = .020$ .

<sup>b</sup> Model  $\chi^2(2) = 7.30; p = .025$ .

\* $p < .05$ ; <sup>+</sup> $p < .10$ .

AT attained marginal significance,  $p = .08$ , in this step, although significant prediction of recognition by AT had been established in previous regressions (see Table 6). The purpose of this analysis was to determine whether the addition of AT to the model significantly reduced the prediction afforded by look duration, and this was indeed the case,  $\chi^2(1) = 4.82, p < .05$ . The marginal effect observed here was likely attributable to a loss of power in the second step of the model, and to the collinearity between look duration and AT.

## DISCUSSION

There are a number of findings from this data set that deserve discussion. These are addressed one at a time in the sections that follow.

### Effect of Choice-Trial Length on Infant Performance

A driving hypothesis behind this study was the possibility that long-looking infants' difficulties on paired-comparison tasks might be a by-product of difficulties in disengaging attention from stimuli during brief choice trials. As such, we increased the length of choice trials from 5 s to 15 s in an effort to allow long-looking infants enough time to disengage attention during choice-trials, and thus perhaps improve paired-comparison performance. The increase in choice-trial length did allow infants more time to compare stimuli, but the initial set of analyses yielded no evidence for either any main or interaction effects for choice-trial length on recognition performance. Those analyses indicated only that briefer look duration (measured across pretest and familiarization periods) predicted a higher likelihood of successful recognition; this is in keeping with past research showing better cognitive performance in infants with briefer look durations.

There are two additional issues of interest here. The first is that all infants were as capable of detecting and showing selectivity for the novel stimulus with 5-s choice trials as they were with 15-s choice trials. This suggests that the response to stimulus novelty within the paired-comparison paradigm is initiated over a relatively rapid time course. The detection and response to novelty within such choice trials has not been subject to fine-grained analyses; the current findings suggest that such analyses might be of interest.

A second issue is that the increase in choice-trial length from 5 s to 15 s more than doubled the amount of SA exhibited by infants. Given previous work on this topic (e.g., Richards & Gibson, 1997; Richards & Lansink, 1997), it was surprising that this increase did not aid in infants' recognition performance. There are several possible interpretations. One is that SA during the actual execution of the discriminative response is irrelevant to the expression of the novelty preference. However, Richards (1997) has demonstrated that novelty preferences are more readily shown when infants are in SA, as compared with other attentional phases. A second possibility is that the amount of time spent in SA does not matter, but rather some other measure of the quality of SA is relevant to recognition performance. Finally, given that these results were obtained with static visual stimuli, it may be that the amount and level of SA is more important to the processing of dynamic stimuli than to static stimuli. This point is raised in another context below.

### Look Duration, HR-Defined Phases of Attention, and Recognition Performance

The current study presents the first set of data that show how HR-defined phases of attention vary with look duration within the context of commonly administered paradigms for infant perceptual-cognitive performance. In virtually all other studies on such HR phases of attention (e.g., Richards, 1997), stimuli and testing parameters vary from the manner in which the paired-comparison task has been typically run (Colombo et al., 1988; Fagan, 1971; Rose, Feldman, & Wallace, 1988).

In this study, OR and SA were not significantly correlated across pretest and familiarization accumulated-looking periods, although the amount of AT was correlated across these phases. Look duration during those periods was consistently and positively correlated with both SA and AT. That is, longer look durations were associated with more time spent in SA and more time spent in AT.

Given previous findings regarding the quality of information processing that presumably takes place

in SA (Richards & Casey, 1992), it is of interest that short-looking infants performed better than long-looking infants despite the fact that they showed significantly less SA during both pretest and familiarization. As discussed above, it may be that some measure of the quality of SA (rather than its temporal quantity) is more relevant to processing; thus, if the rapidity of information processing varies from infant to infant, the amount of time spent in SA will be irrelevant to performance. Perhaps this could be tested if measurement of SA were coupled with finer behavioral measures (e.g., eye tracking). Another possibility is that SA is a more sensitive parameter when the infant is faced with dynamic (rather than static) stimuli. Clearly, it is not adaptive to engage in continued or prolonged fixation of a static stimulus, although it would seem highly advantageous to do so with a dynamic display. Thus, different types of attention may be relevant to the processing of different stimuli. Indeed, the role of the stimulus in analyzing individual differences in infant visual cognition has not been widely investigated.

Finally, logistic regression analyses indicated that the amount of AT (which significantly covaried with look duration and which, like look duration, was significantly correlated across the pretest and familiarization periods) significantly predicted recognition performance. In the last set of analyses, results were obtained that were suggestive of the possibility that AT mediates the association between look duration and recognition performance. This has important theoretical implications for understanding the neurocognitive mechanisms underlying look duration at this age. Previous work (Colombo, Frick, Gorman, & Casbolt, 1997; Frick et al., 1999; Jankowski & Rose, 1997) suggests that both individual and developmental differences in look duration may be related to individual differences in the propensity for shifting and disengaging attention among visual stimuli, or among visual features within stimuli. It may be that difficulty in disengaging from, or the propensity to have attention be captured by, specific local visual features contributes to the difficulties that have been previously reported for longer looking infants on paired-comparison tasks.

Individual differences in look duration have been generally interpreted in terms of differences in the quality or quantity of information processing (Colombo & Mitchell, 1990). The current findings clearly suggest that (at least at 4 months of age) individual differences in look duration are also attributed in part to cognitive functions other than those generally associated with stimulus encoding or processing. AT is analogous to disengagement (Richards & Casey,

1992), in that it represents a continuation of looking after meaningful information processing (which presumably occurs during SA; see Richards, 1989) has ended. The current results thus add to the evidence supporting the hypothesis that individual differences in look duration are related to individual differences in the disengagement of attention. As such, the perseverance of prolonged look duration during the first year of life may, in part, signify a lag in the development of the central nervous system pathways or structures that mediate disengagement. Furthermore, they suggest that individual differences in disengagement, at least in part, contribute to the differences in task performance that have been repeatedly observed between short- and long-looking infants. Our data cannot discriminate among the two extant cognitive–neuroscience models of attentional disengagement in human infants, but given the finding here that disengagement plays a role in infant cognitive performance, critical tests of the models may be more rapidly forthcoming.

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