Infant Visual Attention in the Paired-Comparison Paradigm: Test-Retest and Attention-Performance Relations

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COLOMBO, JOHN; MITCHELL, D. WAYNE; and HOROWITZ, FRANCES DEGEN. *Infant Visual Attention in the Paired-Comparison Paradigm: Test-Retest and Attention-Performance Relations.* CHILD DEVELOPMENT, 1988, **59**, 1198–1210. The visual behavior of infants in the paired-comparison paradigm was assessed with multiple discrimination tasks week-to-week at 4 and 7 months and longitudinally from 4 to 7 months. Results indicated that although task-to-task reliability was extremely variable and typically low, most measures of infants' attention averaged across multiple tasks were reliable from 1 week to the next as well as relatively stable over the longer longitudinal period. Across all groups, infants who had shorter fixations (i.e., more fixations per fixed-exposure period) during the familiarization phase showed higher novelty preferences. While infants' shift rate during test phases was a reliable individual characteristic at 7 months, it was not at 4 months; rather, data suggested that the difficulty of the stimulus discrimination may be related to young infants' shift rate.

For the past 30 years, the human infant's distribution of attention to visual targets (e.g., Bornstein, 1985; Fantz, Fagan, & Miranda, 1975) has been a primary dependent measure in studies of early stimulus processing. One recent focus of research in this area has been the study of individual differences in early attentional patterns, and this research has yielded encouraging results (Bornstein & Sigman, 1986). For example, recent studies of the reliability and stability of visual habituation have shown that various measures of infant attention (particularly duration-based measures) are stable individual characteristics of infants' attentional patterns at 4 months of age and above (Bornstein & Benasich, 1986; Colombo, Mitchell, O'Brien, & Horowitz, 1987a; Rose, Slater, & Perry, 1986; see however, Colombo, Mitchell, O'Brien, & Horowitz, 1987b). Measures of infant attention and inattention also appear to be stable within individuals across visual and auditory habituation paradigms that employ fixation-based techniques (Colombo & Atwater, 1987) and appear to be relatively consistent within individuals across laboratory sessions and social interaction situations (Coldren, 1987). Additionally, several recent reports have documented relations between higher childhood intelligence and shorter fixation durations (Rose et al., 1986; Sigman, Cohen, Beckwith, & Parmelee, 1985) and faster habituation rates (e.g., Ruddy & Bornstein, 1982) during infancy. Similarly, studies using the familiarity-novelty paired-comparison (PC) paradigm (e.g., Fagan, 1971, 1974) have demonstrated modest but consistently positive relations between infant novelty preferences and childhood intelligence (Fagan, 1985; Fagan & McGrath, 1981; Rose & Wallace, 1985). Although these results are encouraging, a number of important issues regarding individual differences in infant visual attention need to be resolved.

First, although novelty preference has been the variable from the PC procedure that has generated the most interest in recent

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times, the procedure yields a number of other measures of interest. Some measures from the familiarization phase are analogous to those from other attentional paradigms, such as fixation duration or interlook interval from the infant-controlled visual habituation method (Horowitz, Paden, Bhana, & Self, 1970). Other measures from the test phase have been the focus of previous investigations, but individual-difference parameters of these measures have not been examined. One such variable is lateral bias (e.g., Cohen & Gelber, 1975), which in very young infants is thought to reflect CNS asymmetry (Liederman & Kinsbourne, 1980a, 1980b; see also Turkewitz, 1980) and has been shown to predict subsequent lateral dominance across various periods during early development (Coryell & Michel, 1978; Gesell & Ames, 1947). Despite much previous interest in this measure, there are no studies of its test-retest reliability or stability across ages. Another variable of interest is infants' fixation shifts (Harris, 1973; Ruff, 1975), which may reflect an active comparison of simultaneously presented stimuli. For example, Ruff (1975) has reported that infants will shift more when paired targets are identical than when they are different. Since this behavior may serve to facilitate stimulus recognition, it is possible that individual differences in infants' shifting might reflect differential "strategies" for dealing with stimulus comparisons. It would be interesting to determine whether such individual differences are reliable across repeated testings and whether such differences affect discrimination performance.

A second issue concerns the two measures of infant attention that have been recently found to correlate with later intelligence. One of these is fixation duration; both Sigman et al. (1985) and Rose et al. (1986) report strong negative relations between fixation durations during infancy and childhood intelligence measures. The other of these measures is novelty preferences, which have in several studies been shown to correlate positively with intelligence in childhood (Fagan & Singer, 1983; Rose & Wallace, 1985). It would be desirable to determine whether these two relations reflect separate and independent components of infant attention that are predictive of later intelligence, or whether they are tapping the same process (i.e., whether "short lookers" also show higher novelty preferences). Some previous research has sought to identify attentional predictors of infant discrimination performance (e.g., DeLoache, 1976; Mitchell, 1987; Mitchell & Steiner, 1984), with equivocal results.

Most of these studies, however, have used visual habituation procedures to familiarize infants with stimuli. The attainment of visual habituation has been traditionally thought to signify complete processing of a stimulus (Sokolov, 1963). The efficacy of particular attentional patterns toward infants' performance may be obscured under such conditions. In fact, the infant control procedure (Horowitz et al., 1970) was ostensibly designed to "equate" stimulus processing across different individual patterns of attention. A *fixed* amount of exposure may thus be better suited to examine the relation between such individual attentional patterns and subsequent discrimination performance. Additionally, these previous studies of attentional predictors of discrimination have as a rule employed posthabituation fixation recovery to a novel stimulus as the measure of individual discrimination performance. The use of recovery in the study of individual differences can be problematic, since the measure has no a priori chance level given that infants receiving no posthabituation stimulus change often may show some regression-based posthabituation recovery (Bertenthal, Haith, & Campos, 1983).

The present studies were undertaken with the following aims. First, we wanted to fill a gap in our current knowledge concerning the short-term reliability and longitudinal stability of infant novelty preferences and other attentional measures from within the PC paradigm. These additional measures include duration of attention and inattention during familiarization, as well as lateral bias and fixation shifts during PC test trials. Second, we wanted to explore the relation between these attentional measures and infants' visual recognition memory under fixed-exposure conditions and with a performance measure perhaps better suited to the study of individual differences. Finally, given the assumption that these relations might be different under different conditions of stimulus discriminability, we attempted to examine these aspects with tasks that were in some way graded in levels of discriminability.

Method

Subjects

Two samples of infants were tested in this study. One was a short-term "week-to-week" sample that consisted of 4-month-olds (N = 42) and 7-month-olds (N = 43) who were tested on a series of PC tasks twice

TABLE 1

HEALTH AND DEMOGRAPHIC CHARACTERISTICS OF INFANTS IN THE STUDY

VARIABLE	WEEK-TO-WEEK 4 Months	WEEK-TO-WEEK 7 Months	MONTH-TO MONTH
Length of gestation (weeks)	40.0 (1.2)	40.0 (1.3)	40.0 (1.3)
Birthweight (grams)	3,554.7 (454.5)	3,570.7 (433.5)	3,543.4 (421.9)
Prenatal complications (%)	25	30	21
Rehospitalizations (%)	2	5	7
Chronic problems (%)	5	5	9
Maternal age (years)	29.4 (3.8)	29.9 (3.7)	30.3 (4.4)
Paternal age (years)	31.1 (4.5)	31.0 (4.1)	31.4 (4.7)
Maternal education (years)	15.0 (2.0)	15.5 (2.0)	15.2 (1.8)
Paternal education (years)	16.5 (2.4)	15.9 (2.1)	16.3 (2.3)
No. of siblings	.7 (.7)	.7 (.8)	.8 (.8)

NOTE.—Standard deviations are in parentheses.

within a span of 2–3 weeks (mean intertest interval = 8.2 days). Eighteen of these 4-month-olds were excluded from reliability analyses because they failed to return for a second visit (N = 6) or because they failed to complete any tasks on the second week due to fussiness (N = 12). Similarly, nine 7-month-olds were excluded from reliability analyses because they failed to return for a second visit (N = 3), failed to complete any tasks on the second week due to fussiness (N = 2), or because of experimenter error (N = 3).

A second "month-to-month" sample (N = 52) was tested once at 4 months of age and then again at 7 months on the same tasks as the week-to-week sample. Eighteen of these infants were excluded from stability analyses because they failed to return for their second visit (N = 12) or because they failed to complete any tasks on one visit (N = 6).

Demographic and health data were collected on each subject (see Table 1). These measures did not relate to any of the infants' attentional measures, and there were no significant differences between any of the samples tested.

Stimuli and Design

The stimuli chosen for the familiarization-novelty tasks were letters of the alphabet. These stimuli were chosen because of the extensive parametric data already available on the discriminability of various letter pairings both with human (e.g., Townsend, 1971) and infrahuman (Blough, 1981) subjects. This previous work allowed the construction of an a priori scale for the scaling of discrimination difficulty for particular letter pairings. We selected 10 letter pairings (four difficult tasks, three moderate tasks, three easy tasks) from confusion matrices derived from discrimination data collected from pigeons (Blough, 1981). Difficult discriminations were pairings of the letters B-P, W-N, X-Y, and D-O; moderate discriminations were pairings of T-J, A-R, and E-Z; easy discriminations were pairings of G-V, H-S, and C-M. We divided the 10 discrimination pairings into two sets of five, with one set being presented per session. Each set consisted of two "difficult" discrimination tasks plus three others which included at least one each of a "moderate" and "easy" task (see Table 2). Although the order of presentation of the tasks was held constant across the two sets, the task order was arranged such that analyses of infants' performance on the basis of task difficulty would not be confounded with patterns of performance that could be interpreted as fatigue (i.e., a decline in performance with repeated testing) or practice (i.e., an improvement in performance with repeated tasks) effects. Furthermore, infants were assigned to one of two conditions across which the stimulus serving as the familiar during the discrimination task was varied, as was the order of presentation of the task sets.

Apparatus and Procedure

Infants were seated on their parents' laps in a 2 × 2-m booth darkened on three sides by black fabric and on the fourth side by a

TABLE 2

STIMULUS PAIRINGS AND PRESENTATION ORDER

	TASK PAIRING				
	1	2	3	4	5
Condition 1:					
First visit	B-P	G-V	A-R	W-N	C-M
Second visit	X-Y	H-S	T-J	D-O	E-Z
Condition 2:					
First visit	Y-X	S-H	J-T	O-D	Z-E
Second visit	P-B	V-G	R-A	N-W	M-C

NOTE.—The first stimulus listed for each pairing is the familiarized stimulus. The first lateral position of the novel stimulus for the first task was assigned randomly and was alternated for subsequent tasks.

black wall. A 1.0 × 0.7-m translucent rear-projection screen was centered in the wall, with 10-mm peepholes to the left and right of the screen.

Infants were presented with up to five familiarization-novelty tasks per visit. For each task, a stimulus slide was rear-projected onto the center of the screen until the infant had accumulated some amount of fixation time. The amount of this familiarization time varied with the age of the infant; 4-month-olds received 20 sec and 7-month-olds received 10 sec. Following the accumulation of familiarization time, the familiarized stimulus was projected onto the screen simultaneously with a novel stimulus for two PC trials. Stimuli were projected to the left and right of midline (subtending a total visual angle of 39°), and infants were required to accumulate a predetermined amount of fixation time during these trials. Again, the amount of accumulated fixation time during these test trials varied with the age of the infant: 4-month-olds received 10-sec trials, while 7-month-olds received 5-sec trials. The lateral position of the two stimuli was reversed during the second PC trial relative to the first trial in order to provide within-subject control for infant lateral bias (Cohen & Gelber, 1975). The initial lateral position of the novel stimulus (i.e., novel stimulus right or novel stimulus left) during the first discrimination task was randomly assigned and was alternated across subsequent tasks. The familiarization-novelty tasks immediately followed one another.

Fixations were recorded by an observer (blind to stimulus identity and position) who monitored corneal reflections from the peephole to the left of the projection screen. A microcomputer timed fixations and controlled slide changes. Interobserver reliability was assessed for 40 tasks, and Pearson coefficients for the two observers' records were +.95 for novelty preferences, +.92 for number of fixations during familiarization, and +.90 for number of shifts during PC trials. Reliabilities did not vary with the age of the infant.

Variables of Interest

Familiarization Phase

Number of fixations.—This variable was taken as an index of the length of fixations for individual infants, since the number of fixations infants made in accumulating the fixed amount of familiarization time would be inversely proportional to the length of their fixations during that period. While a "mean fixation duration" for the familiarization period can be derived by dividing the fixed accumulation time by the number of fixations, we have found the simple frequency-of-fixation measure to be superior to the derived mean fixation duration for two reasons. First, the mean fixation so derived does not take into account the fact that the last fixation will be cut off when the infant reaches the required accumulation time. The variable thus does not produce a truly accurate mean fixation measure. Second, the distribution of the mean fixation measure is, like all fixation duration measures (Bornstein & Benasich, 1986; Colombo et al., 1987a), severely skewed. This skewedness will attenuate the sensitivity of parametric correlational statistics, such as Pearson's r. We found the number-of-fixations measure to be normally distributed, and therefore more appropriate for the correlational methods employed in this study. In situations where two age groups (and therefore two different familiarization times) are to be compared (such as in Table 3), this variable has been adjusted to a rate (number of fixations per 10 sec).

TABLE 3

Means (and Standard Deviations) for Measures of Interest

	Week-to-Week				Month-to-Month	
	4 Months		7 Months			
	Week 1	Week 2	Week 1	Week 2		
No. of fixations (per 10 sec)	4.3 (1.8)	4.6 (2.1)	4.5 (1.5)	4.2 (1.2)	4.0 (1.7)	4.4 (1.6)
Proportion of time off stimulus	1.6 (1.2)	1.6 (1.2)	1.1 (.8)	1.1 (.8)	1.4 (1.4)	1.1 (.6)
Rate of shifts (per sec)	.31 (.21)	.29 (.16)	.61 (.17)	.54 (.30)	.45 (.17)	.60 (.20)
Lateral bias (% right)	.52 (.16)	.46 (.20)	.50 (.12)	.48 (.16)	.48 (.16)	.46 (.12)
Novelty preferences (%)	.57 (.10)	.59 (.10)	.57 (.09)	.55 (.07)	.56 (.08)	.55 (.07)

Proportion of time spent off stimulus.—Infants were required to accumulate a constant amount of fixation time to the stimulus, but the amount of real time taken to accumulate this could vary. Therefore, infants who spent more time looking away from the stimulus would take longer to accumulate the required fixation time. This amount of "off time" may indicate the degree to which infants were "on task" (e.g., Mitchell & Steiner, 1984), may somehow interfere with the infant's ability to form a memory (Rose, 1981), or may reflect the infant's tendency toward exploration of the visual environment beyond the presented stimuli. We derived a measure of this "off time" with the following formula:

$$\frac{TET - FT}{FT},$$

where TET equals the total elapsed time of the familiarization phase, and FT equals the accumulated fixation time required for an infant's particular age group. A ratio of 1.0 indicates no "off time," and again, using a ratio yields a measure that is directly comparable across the different study times employed for the 4- and 7-month-olds.

Test Phase

Shift rate.—Ruff (1975) has reported that infants will shift (i.e., alternately fixate) more under conditions where simultaneously presented stimuli are identical than when they are discrepant. This suggests that such a measure may be sensitive to infants' perception of the similarity, or discriminability, of paired targets. Therefore, we coded any alternate fixation as a shift and derived a measure of shift rate by dividing the number of alternate fixations by the accumulation criterion of the choice trials (i.e., 10 or 20 sec).

Lateral bias.—Infant lateral bias has been a methodological obstacle for investigators studying early stimulus processing (Cohen & Gelber, 1975), as well as a phenomenon of interest per se (e.g., Turkewitz, 1980), given the belief that it reflects some aspect of the infant's neurological organization. Surprisingly, there has been no study of its individual reliability or stability across time. We calculated a measure of lateral bias by dividing the total of looking time to the right stimulus across both test trials by the total time of both test trials. This yields a ratio that varies from 1.00 (a total right bias) to 0.00 (a total left bias) with 0.50 indicating no bias.

Novelty preferences.—The percentage of time infants spend fixating the novel stimulus during the test phase has a long history in the field as a measure of early recognition memory (Fagan, 1985). Percentages significantly exceeding chance (0.50) suggest stimulus discrimination and recognition memory (Fagan, 1971).

Results

Preliminary Analyses

Preliminary analyses performed on the various measures did not reveal any significant effects due to infant gender. Furthermore, except for one instance, analyses of the measures as a function of task order, familiar-stimulus condition, or, in the week-to-week sample, first versus second visit did not reveal any significant effects. Therefore, neither the position of the task during the session nor the letter serving as the familiar stimulus had any effect on the infant's attention to, or discrimination of, the stimuli involved. The one exception to this was an order effect for stimulus set 2 (X-Y, H-S, A-R, D-O, E-Z) in the number of shifts for the 4-month-olds, $F(4,281) = 3.37$, $p < .01$; a Tukey HSD test determined that this effect was due solely to infants' shifting significantly more during the first pair (X-Y; 8.3 shifts) than during the second (H-S; 6.9 shifts) and third (E-Z; 6.3 shifts) pairs. Means for the other two stimulus pairs in this set were 7.3 (W-N) and 7.4 (E-Z). This order effect will be important to consider during the task-difficulty analyses described below.[1]

Finally, a set of analyses were performed that compared whether the two age groups involved differed as a function of sample (i.e., week-to-week vs. month-to-month) on the measures specified above. No significant differences were found.

Normative Analyses

T tests for age differences were computed on each of the variables of interest (see Table 3 for means). The only age difference consistent across both samples and across assessments was on shift rate. Four-month-olds had lower shift rates than 7-month-olds in the week-to-week sample, $t(60) = 4.09$, $p < .01$, and the 4-month-olds seen in the month-to-month sample had lower shift rates than when they were seen again at 7 months of age, $t(37) = 2.83$, $p < .01$. Another difference observed was that 4-month-olds in the week-to-week sample had significantly higher proportions of time spent off the stimulus during the familiarization phase, $t(60) = 2.31$, $p < .025$, but while this trend was repeated for infants seen month-to-month (see Table 3), the age difference for this sample was not statistically significant, $t(37) = 1.10$, N.S.

Infants' mean per-week novelty scores exceeded chance (.50) at every assessment. For the week-to-week samples, 4-month-olds' preferences were .57 on week 1, $t(34) = 4.37$, $p < .001$, and .59 on week 2, $t(23) = 4.62$, $p < .001$, and the 7-month-olds' preferences were .57 on week 1, $t(39) = 5.36$, $p < .001$, and .55 on week 2, $t(38) = 4.36$, $p < .001$. For the month-to-month sample, preferences were .56 at the 4-month assessment, $t(45) = 5.25$, $p < .001$, and .56 at the 7-month assessment, $t(39) = 4.94$, $p < .001$. The fact that there were no age differences in infants' discrimination performance suggests that the adjustment of familiarization time properly equated the tasks across the two ages tested.

One additional difference of interest not reflected in Table 3 is that 4-month-olds completed significantly fewer tasks than 7-month-olds in the week-to-week sample. On the first visit, the respective means for number of tasks completed for the 4- and 7-month-olds were 3.5 versus 4.9, $t(73) = 6.32$, $p < .001$, and 2.7 versus 4.7, $t(73) = 5.14$, $p < .001$, on the second visit. This difference was not present in the month-to-month sample (the mean number of tasks completed was 4.0 vs. 4.1 at 4 and 7 months, respectively, $t[37] = 0.37$, N.S.). While it is unclear why this age effect would appear in one sample and not the other, the difference has important implications for the assessment of week-to-week reliabilities and is discussed further below.

Test-Retest Correlations

Intercorrelations of discrimination items.—The basic question of test-retest reliability involves the task-to-task correlations of infant performance. We calculated these correlations for infants' novelty preferences, given that this has been the measure of most interest to researchers in infant perception and discrimination. The correlation matrices shown in Table 4 include data from all infants (i.e., both week-to-week and month-to-month samples) at 4 months and all infants at 7 months. As is evident from Table 4, the internal consistency of infant novelty preferences is extremely variable and, on average, somewhat low. The mean task-to-task correlation for 4-month-olds is +.20, while the mean task-to-task correlation for 7-month-olds is +.24. These results are comparable to those reported in other previous studies with fewer tasks (Fagan, 1984; Rose & Feldman, 1987).

Week-to-week reliabilities.—We also examined the reliability between infants' mean attentional and discrimination performance on one week and that on the next week. These correlations (see Table 5) indicated moderate reliability of these measures. It should be noted that the significance of these reliability correlations is evaluated with one-tailed *p* values because we would not theoretically expect inverse test-retest relations. Among those variables exhibiting statistically significant reliability were infants' number of fixations during familiarization, proportion of time off stimulus during the familiarization phase, and novelty preferences. While the reliability of infants' lateral bias was not significant within either of the age groups separately, the magnitude of the relation was consistent at both ages and in fact did reach

[1] A similar pattern of results was observed for stimulus set 1. The mean number of shifts decreased across the first three stimulus pairs (10.4 for B-P, 8.0 for G-V, and 6.8 for T-J), increased for the fourth (7.8 for W-N), and dropped slightly for the fifth (7.2 for C-M). However, there were no significant differences among the pairs for this set.

TABLE 4

INTERNAL CONSISTENCY OF NOVELTY PREFERENCES

	DIFFICULT			MODERATE			EASY		
	W-N	X-Y	D-O	T-J	A-R	E-Z	G-V	C-M	H-S
4-month-olds:[a]									
B-P	.24	.06	−.02	.48*	.11	.09	.71*	.22	−.04
W-N		.07	.19	.45*	−.13	.33	.25	.55*	−.15
X-Y			.23	−.02	.34*	.27	.25	.20	.51*
D-O				.01	.61*	.49*	.16	.24	.34*
T-J					−.08	.19	.48*	.28	−.17
A-R						.24	.14	−.08	.45*
E-Z							.30	.24	.08
G-V								.26	.00
C-M									.00
7-month-olds:									
B-P	.77*	−.10	.00	.74*	−.08	.00	.75*	.54*	−.01
W-N		.11	.17	.56*	.03	.08	.61*	.53*	.09
X-Y			.50*	−.13	.60*	.29	.11	−.01	.51*
D-O				−.09	.36*	.45*	.01	−.02	.43*
T-J					−.12	−.07	.70*	.45*	−.05
A-R						.31*	.25	.24	.49*
E-Z							−.07	.26	.41*
G-V								.56*	.02
C-M									−.14

[a] Minimum pairwise ($N = 35$).
[b] Minimum pairwise ($N = 40$).
* $p < .01$ (one-tailed).

statistical significance when the two age groups were combined ($r = +.33$, $p = .01$). One surprising age difference was that the week-to-week correlation for shift rate was highly significant for 7-month-olds ($r = +.56$), but not at 4 months ($r = +.10$).

As we have noted previously, 4-month-olds in this sample completed significantly fewer tasks than did the 7-month-olds. This situation allowed a within-sample test of the possibility that test-retest reliabilities might increase as a function of the number of items involved. We therefore examined the reliabilities of these measures as a function of the number of tasks completed by the 4-month-olds (see Table 6). The reliability of number of fixations, proportion of time off stimulus, and novelty preferences generally increased with the number of tasks completed, thus supporting this hypothesis and eliminating the small differences in reliability observed between the 4- and 7-month-olds evident in Table 5.[2] One interesting exception to this general trend is lateral bias, the reliability of which actually decreases with increased tasks. One possible explanation for this is that those 4-month-olds who have enough self-regulation to complete multiple tasks may also be mature enough to show less lateral bias. The reliability of shift rate at 4 months remained low and nonsignificant, regardless of the number of tasks involved.

Longitudinal stabilities.—Table 7 presents the stability correlations for infants' mean attentional and discrimination measures at 4 months of age with those at 7 months of age (again, one-tailed tests are used). Variables that were statistically reliable week-to-week at 4 and 7 months (number of fixations during familiarization, proportion of time off stimulus during familiarization, and novelty preferences) also showed statistically

[2] This result is not attributable to higher task-to-task reliability of attention in infants who completed more tasks. We computed task-to-task matrices (similar to those shown in Table 4) for those 4-month-olds who consistently completed many tasks (4 or 5) on both visits and for those who completed fewer tasks on one visit or other. The matrix of task-to-task correlations for those infants completing many tasks was not appreciably different from that for infants who completed fewer tasks.

TABLE 5

WEEK-TO-WEEK RELIABILITIES OF INFANT ATTENTIONAL MEASURES

	4 MONTHS (N = 22)	7 MONTHS (N = 40)	BOTH AGES (N = 62) Simple r	Age Partialed
Number of fixations	.54**	.48**	.34**	.53**
Proportion of time off stimulus	.48*	.54**	.62**	.49**
Shift rate	.10	.56**	.67**	.37**
Lateral bias	.31	.29	.33**	.33**
Novelty preferences	.40*	.51**	.39**	.39**

NOTE.—4-month correlations are based on infants who completed at least two novelty tasks per visit. Age-partialed test-retest correlations are presented to control for small developmental differences in attentional distributions.
* $p < .05$ (one-tailed).
** $p < .01$ (one-tailed).

significant stability across the period from 4 to 7 months, although the magnitude of these longitudinal coefficients is lower than that observed from one week to the next. The stability of lateral bias was statistically significant across this period as well. The longitudinal correlation between shift rate at 4 and 7 months was not statistically significant.

Prediction of Novelty Preferences from Attentional Measures

We next examined the relations between various measures of infants' attentional behavior during the familiarization and test phases and their discrimination-recognition performance (see Table 8). In all cases but one, the number of fixations infants made during the familiarization phase was positively related to their overall discrimination performance; that is, infants with shorter duration fixations during the familiarization sequence performed better on the subsequent novelty tests. Only at the 7-month assessment of the month-to-month sample did this correlation not reach statistical significance, and even there it is marginally ($p < .07$, two-tailed) significant. When data are combined across both samples, this relation is significant at the $p < .001$ level for both age groups: $r = +.41$ for the 4-month-olds, and $r = +.36$ for the 7-month-olds.

TABLE 7

STABILITY OF INFANT ATTENTIONAL MEASURES FROM 4 TO 7 MONTHS

	r (N = 38)
Number of fixations	.33*
Proportion of time off stimulus	.27*
Lateral bias	.31*
Shift rate	.07
Novelty preferences	.34*

* $p < .05$ (one-tailed).

TABLE 6

WEEK-TO-WEEK RELIABILITIES OF 4-MONTH-OLDS' ATTENTIONAL MEASURES: EFFECT OF NUMBER OF MEASUREMENTS

	MINIMUM NO. TASKS PER VISIT: 1 (N = 24)	2 (N = 22)	3 (N = 14)
Number of fixations	.56*	.54*	.64*
Proportion of time off stimulus	.45*	.48*	.71*
Shift rate	.18	.10	.09
Lateral bias	.37*	.31	−.03
Novelty preferences	.26	.40*	.45*

*$p < .05$ (one-tailed).

TABLE 8

ATTENTIONAL PREDICTORS OF NOVELTY PREFERENCES AT 4 AND 7 MONTHS

	WEEK-TO-WEEK			MONTH-TO MONTH	COMBINED
	Week 1 (N = 35)	Week 2 (N = 22)	Both (N = 22)	(N = 38)	(N = 60)
4 months:					
No. of fixations	.38*	.33	.40*	.40*	.41*
Proportion of time off stimulus	.25	.40*	.39*	.47*	.28*
Lateral bias	−.28	.12	−.07	−.05	−.11
Shift rate	−.06	−.03	−.13	−.05	−.15
	Week 1 (N = 40)	Week 2 (N = 38)	Both (N = 38)	MONTH-TO MONTH (N = 38)	COMBINED (N = 76)
7 months:					
No. of fixations	.37*	.45*	.51**	.28	.36*
Proportion of time off stimulus	.30	.09	.25	.04	.13
Lateral bias	.04	.20	.27	.18	.22
Shift rate	−.04	.13	.06	−.01	.02

* $p < .05$ (two-tailed).
** $p < .01$ (two-tailed).

For 4-month-olds, we also observed positive relations between infants' proportion of time off the stimulus during familiarization and their novelty preferences. This relation was not statistically significant on the first week, but it is significant on week 2 and is significant when infants' performance across both weeks is averaged. This finding also was replicated in the 4-month assessment for the month-to-month sample. It appears that this relation may be attributed to the fact that proportion of time off the stimulus and number of fixations is highly correlated at 4 months ($r = +.57$, $p < .01$) but less so at 7 months ($r = +.34$, $p < .05$), at which time there is no significant correlation between proportion of time off the stimulus during familiarization and novelty preferences (see Table 8). None of the other attentional measures significantly predicted novelty preferences.

While the results of this analysis link shorter patterns of looking with higher novelty preferences, it is not clear whether these correlations actually represent a recognition-memory deficit in infants with patterns of longer fixations, or a heightened response to novel stimuli in the shorter-looking infants. To try and address this question, we split the samples of infants at each assessment at the median for number of fixations during familiarization and tested whether infants with patterns of long fixations (i.e., those infants with fewer fixations during familiarization) actually discriminated the visual targets involved (i.e., had novelty preferences greater than chance). At all assessments, tests of infants' mean per-week (in the week-to-week sample) or pre-assessment (in the month-to-month sample) novelty preferences against the expectation of chance (.50) indicated that these subjects did exhibit discrimination performance above chance (the minimum t value was 2.22, with all results exceeding at least the .03 level of significance).[3] These results suggest that the positive correlations between number of fixations during familiarization and novelty preferences may be more confidently attributed to a higher *degree* of preference for novelty in short-looking infants than to a failure to discriminate visual targets by infants with longer fixation patterns.

Task Difficulty Analyses

A last set of analyses focused on the a priori difficulty gradient for the letter-discrimination tasks. We first performed a task-difficulty ANOVA on infants' novelty preferences averaged within a priori dimensions of difficult, moderate, and easy stimulus pairs,

[3] The differences in mean novelty preferences for the two groups of infants obtained with this median split were .59 versus .55, respectively, for short- versus long-looking infants at 4 months and .58 versus .53, respectively, for short- versus long-looking infants at 7 months.

but this analysis did not yield significant differences for either age group. The mean 4-month-olds' novelty preferences were .58, .56, and .55 across the difficult, moderate, and easy tasks, respectively, while the mean 7-month-olds' novelty preferences was .55 across all three types of tasks.

The second analysis we performed on the basis of the a priori task-difficulty levels involved infants' shift rate as a function of the discrimination pairs. Ruff (1975) found previously that 5-month-old infants shifted more during PC tasks when the discrimination stimuli were similar than when the stimuli were discrepant. Based on this finding, we expected an increase in infants' shift rate with increases in task difficulty. To test this, we collapsed infants' shifts by categories of difficult, moderate, and easy tasks, and compared shifts through separate one-way (3: difficulty level) ANOVAs for each of the two age groups. Although the 7-month-olds did not shift differently as a function of the discriminability of the stimulus pairs, $F(2,574) = 0.29$, N.S., the 4-month-olds did exhibit the expected pattern, $F(2,391) = 7.13$, $p < .001$. The 4-month-olds' mean shift rates were 0.43 per second for difficult tasks, 0.32 per second for moderate tasks, and 0.35 per second for the easy tasks, with the rates for the difficult pairs being significantly different from the other two pairs ($p < .05$, Tukey HSD test). It is important to note here that difficult discriminations were placed first in each of the sets, and that it might be possible to observe an artifactual effect for task difficulty if infants decreased their shifting (i.e., fatigued) across repeated tasks. In fact, as we have pointed out above, we did observe an order effect in shifting for the 4-month-olds across the second stimulus set (B-P, G-V, T-J, W-N, and C-M). However, while there were significant differences between the number of shifts in the B-P pair and the two following pairs (G-V and T-J), there was no difference between the B-P pair and the second difficult pair (W-N), which occurred fourth in the sequence (i.e., following the G-V and T-J pairs). In fact, for both stimulus sets, shifting increased across the third to the fourth stimulus pair, which reflected a transition from an easy to a difficult discrimination. While these results await confirmation within a design in which stimulus order is completely counterbalanced (a design that is not always compatible with individual differences research), the pattern of results observed here appears to more strongly support the task-difficulty interpretation than the order-effect interpretation.

General Discussion

This study provides several important pieces of information that serve to integrate several aspects of individual differences in infant attention and discrimination performance.

First, the results of test-retest analyses indicate that novelty preference is not the only measure to reflect stable individual differences in attention within the PC paradigm (see also Rose & Feldman, 1987). In fact, nearly all measures of infants' visual attention showed good reliability from one week to the next and moderate stability across the period from 4 to 7 months of age. With regard to week-to-week reliability, only infants' shift rate showed age-related differences, as 7-month-olds showed good short-term reliability, and 4-month-olds showed none. Surprisingly, the reliability of lateral bias was not statistically significant over the short term for either age group, but the correlation did reach statistical significance when the samples were combined. Across the longer period from 4 to 7 months of age, these same attentional characteristics appear to be also moderately stable, although, as might be expected, these correlations are generally lower than those observed for the week-to-week measurements. Only the stability correlation for shift rate did not reach statistical significance.

A second conclusion that may be drawn from these data is that the reliability of infant measures is very greatly affected by the number of assessments taken, such that a single assessment is probably inappropriate for any study of individual differences during infancy. The data from which this conclusion is drawn come from two sources. The first is a series of analyses of the task-to-task reliability of novelty preferences. While infants' average novelty preferences were both reliable across the short term and stable across a longer-term 3-month period from 4 to 7 months of age, task-to-task (i.e., item) intercorrelations of novelty preferences did not exhibit much consistency within either age group. According to Table 4, a study of individual differences that employed a single assessment of novelty preferences might observe reliabilities as high as +.77 or as low as −.17, each prompting different (and opposite) conclusions about individual differences in infant attention, neither of which would accurately reflect the results of studies using multiple measurements. A second source for the conclusion regarding number of assessments and the reliability of those assessments comes from the increase in reliability seen on most attentional measures with increases in the number of tasks completed by the 4-month-olds. Since the use of multiple assessments has been more the exception than the rule in any area of infant research, this may account for why previous studies have reported low reliability for measures of infant attention (e.g., McCall, 1979; see also Colombo et al., 1987a), why estimates for these reliabilities have varied widely (e.g., Bornstein & Benasich, 1986; Byrne, Clark-Tousenard, Hondas, & Smith, 1984; Colombo et al., 1987a; Rose et al., 1986), or why the patterns of prediction to or from these measures has been somewhat erratic (e.g., Miller et al., 1977, 1979; Moss, 1987; Rose et al., 1986; Ruddy & Bornstein, 1982). These results may also have important implications for other measures of infant development for which single measurements have heretofore exhibited little test-retest reliability and very low predictive value, such as the Brazelton (1986) Neonatal Behavioral Assessment Scale (e.g., Horowitz, Sullivan, & Linn, 1978; Lancioni, Horowitz, & Sullivan, 1980). While our results of course do not preclude the possibility of positive findings with single assessments, they do indicate that progress in our understanding of at least infant attention and cognition might be improved by multiple-task strategies.

Third, these data integrate a series of recent findings regarding the predictive validity of measures from the habituation-dishabituation paradigm and the PC paradigm. Within the PC paradigm, infants' novelty preferences have been repeatedly found to correlate with childhood intelligence (e.g., Fagan & Singer, 1983), while from habituation techniques, infants' fixation durations (Rose et al., 1986; Sigman et al., 1985) have been found to correlate negatively with later intelligence. With the present data, we have demonstrated the individual consistency of both infants' fixation duration (see also Colombo et al., 1987a, 1987b) and novelty preferences (see also Rose & Feldman, 1987) within the paradigm (see also Colombo & Atwater, 1987).

Most importantly, the present data concurrently link short-looking with higher magnitude novelty preferences, thus suggesting that these two findings may reflect a unitary attentional process with some long-term meaning. This finding has several possible interpretations, primarily dependent on one's interpretation of novelty-preference magnitude. If the degree of novelty preference above chance is taken as an index of the *quality* of the infant's memory for the stimulus, then short-looking infants enjoy some advantage in processing the familiar stimulus. This advantage may be attributed to several possible mechanisms. We have elsewhere suggested that shorter fixations may imply faster stimulus processing (Colombo et al., 1987a). Alternatively, the fact that shorter fixations permit successive refixations (and a corresponding strengthening of the "schema" for the exposed stimulus) during familiarization may be responsible for this advantage. Finally, it is possible that shorter fixations more closely mimic "distributed" (as opposed to "massed") practice and thus enhance the quality of memory.

If novelty preferences are more literally interpreted as a positive response to novelty, perhaps as an index of exploratory behavior or motivation, the interpretation may be that short-looking infants are simply "exploring" the environment more during familiarization. Significant positive correlations between number of looks and proportion of time spent off the stimulus during famliarization at 4 and 7 months of age (*r*'s = +.56 and +.34, respectively) also provide support for this latter interpretation. Sternberg and his colleagues (Berg & Sternberg, 1985; Sternberg, 1985) have hypothesized that the positive response to novelty comprises one important component of mature intellectual functioning, and have suggested that this is the component responsible for the continuity in mental development demonstrated by positive correlations between infant novelty preferences and later intelligence. Our results clearly support the feasibility of this position.

In any case, in closing the discussion on these findings, we would add the caution that any advantage in performance enjoyed by short-looking infants may be limited to situations in which these infants repeatedly return to fixate the stimulus, either because they are internally motivated to do so, or (as is the case with the accumulated-fixation techniques used in this study) because the method forces them to do so.

A last series of findings concern infants' fixation shifts during the test phase. Older infants had higher shift rates than younger infants. We cannot definitively rule out the possibility that this is an artifact of longer test trials endured by the 4-month-olds; for example, if shifting takes place exclusively during the first 5 or 10 sec of each test trial for any age group, then shift rates would be lowered in proportion to the extension of test-trial durations beyond this initial burst of shifting. However, increased shifting with age has been observed with an adaptation of the PC paradigm for auditory stimuli where test-trial length was held constant (Colombo & Bundy, 1983). If future research shows this difference is in fact a developmental one, it may be attributable to either enhanced motoric ability in older infants, or an increased interest in stimulus comparisons (or the task itself) in older infants. Our data also suggest that the amount of shifting between stimuli by 4-month-olds may be determined by the difficulty of the discriminations. These results are interesting for several reasons. First, they support and extend Ruff's (1975) earlier contentions regarding the sensitivity of this measure, and suggest that although infants may well be able to solve particular visual tasks across a continuum of discriminability, different (strategic?) patterns of visual behavior may be adopted to adjust for the difficulty of the task. Second, they provide indirect support for the infrahuman (Blough, 1981) and adult (e.g., Townsend, 1971) literatures on the relative confusability of letter pairs. Finally, the fact that 7-month-olds did not increase their shift rates in order to solve the more difficult discriminations may imply that 10 sec of familiarization was more than sufficient to allow processing of these stimuli. This suggests that it may be fruitful to explore infant discrimination and memory at exposure levels that are much lower than those typically employed in the field.

Our findings that fixation shifts may increase both as a function of age and the difficulty of the task seem difficult to reconcile at face value. The counterpoint of these results suggests that there may be at least two determinants of fixation shifts, one developmental in nature, and the other related to the discriminability of the stimuli. The fact that shift rate was among the most reliable individual difference measures at 7 months but showed little individual reliability at 4 months also suggests that this behavior may represent more than one process. While our data do not allow us to draw any further conclusions regarding what processes this measure might represent, we hope that these results will generate further interest in this measure for future research.

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