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Processing Speed in the 1st Year of Life: A Longitudinal Study of Preterm and Full-Term Infants

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Processing speed was assessed at 5, 7, and 12 months in full-term and preterm infants (birthweight < 1,750 g). Speed was gauged directly in a new task by presenting infants with a series of paired faces, one that remained the same across trials and one that changed; trials continued until infants showed a consistent novelty preference. At all ages, preterms required about 20% more trials and 30% more time than full-terms to reach criterion. Among preterms, slower processing was associated with greater medical risk (e.g., respiratory distress syndrome). Developmental trajectories for speed (and attention) were similar for both groups. Thus, the deficits in processing speed previously found for preterms in childhood are already present in the 1st year of life.

Historically, processing speed has played a pivotal role in theoretical conceptions concerning the foundations of cognitive ability in adults (see Deary, 1988; Detterman, 1987a, 1987b; Jensen, 1992; Nettlebeck, 1987; Vernon, 1987) and is thought by many to underlie the principal component of general intelligence, or *g*. Correlations of reaction time with *g* are consistent with this idea, as are correlations between *g* and inspection time (defined as the minimum time needed to make accurate discriminations between two tachistoscopically presented stimuli).

Age-related changes in speed of information processing appear to be quite pronounced from early childhood through adolescence, improving in concert for tasks as diverse as memory search, mental rotation, visual search, analogical reasoning, and mental arithmetic (Hale, 1990; Kail, 1986, 1988). The similarity and generality of age differences across tasks led Kail (1991) to suggest that age-related increases in the ability to perform many cognitive tasks are due to a central limiting factor—processing speed—that increases with age, rather than simply to the acquisition of distinct task-specific skills. These age-related changes in processing speed are thought to mediate, at least partially, age-related changes in other aspects of cognition, including verbal ability, spatial ability, and reasoning (see Kail, 1991; Salthouse, 1996). Fry and Hale (1996) found evidence for a developmental cascade between 7 and 9 years in which information processing became faster, leading to improvements in memory, which in turn led to increases in intelligence.

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Many of the tasks thought to depend on processing speed are the very ones on which preterm infants (*preterms*) often perform poorly (for reviews, see Aylward, Pfeiffer, Wright, & Verhulst, 1989; Escobar, Littenberg, & Petitti, 1991; Hoy, Bill, & Sykes, 1988). These include measures of intelligence, language, and academic achievement, such as reading, arithmetic, and spelling. In fact, the mean IQ of preterms born at very low birth weight (VLBW; <1,500 g), though generally in the normal range, averages as much as 10 points lower than that of full-term infants (*full-terms;* e.g., Rose, Feldman, Wallace, & McCarton, 1991). The cognitive difficulties seen in preterms are evident even when samples are restricted to those without severe neurological impairment and differences due to socioeconomic status (SES) and neonatal health are controlled (e.g., Hack et al., 1992; Rickards et al., 1993; Ross, Lipper, & Auld, 1991; for reviews, see Aylward et al., 1989; Escobar et al., 1991; Hoy et al., 1988). In our own lab (Rose & Feldman, 1996), we found that VLBW preterms were slower than full-terms on assessments of processing speed at 11 years. Moreover, measures of processing speed accounted for as much as 60% of the 10-point IQ difference that existed between the two groups. Thus, speed of processing plays a pivotal role in more general aspects of cognition.

Recent findings suggest that individual differences in processing speed may have their roots in infancy. First, in a factor-analytic study of infant measures, those considered to reflect speed (reaction times [RTs] and look duration) defined a primary factor, accounting for 21% of the explained variance (Jacobson et al., 1992). Second, in a canonical analysis relating cognitive measures from infancy to those at 11 years, a single variate emerged that could best be interpreted as representing speed (Rose & Feldman, 1995). Third, RTs obtained in infancy (using the visual expectation paradigm, see Haith, Wentworth, & Canfield, 1993) have been found to relate to childhood processing speed and IQ (Dougherty & Haith, 1997). Fourth, performance on infant tasks thought to depend on speed, such as recognition memory (Colombo, 1993), have been found to relate to measures directly tapping speed in later childhood (Rose & Feldman, 1995, 1997).

Some of the cognitive tasks on which preterms perform poorly in the 1st year of life appear to involve processing speed. Evi-

dence, although somewhat indirect, comes from paired-comparison and habituation paradigms. In these studies, preterms are tested at “corrected age,” that is, age from the expected date of birth, so that performance differences are not confounded with biological maturity. In one study (Rose, 1980), 6-month-olds were tested for the recognition of abstract patterns and faces. Initially, when familiarization times were quite brief (5 to 20 s, depending on the problem), only full-terms exhibited significant novelty preferences. (Similar results were noted at 4 months by Sigman & Parmelee, 1974, and at 2, 4, and 6 months by Holmes, Reich, & Gyurke, 1989.) It is noteworthy, however, that preterms’ performance improved dramatically when familiarization times were increased (Rose, 1980), suggesting that they were slower in processing the stimuli than their full-term counterparts. These findings of slower processing were reinforced and extended in a second study (Rose, 1983), in which the poorer recognition memory of preterms was found at 6 and 12 months. Here, infants were tested for recognition of three-dimensional shapes after familiarization times of 10, 15, 20, and 30 s. At both ages preterms needed longer familiarization time than full-terms before they exhibited reliable novelty preferences (30 s vs. 15 s at 6 months; 20 s vs. 10 s at 12 months). Thus, although both groups encoded the stimuli faster as they got older, preterms continued to require more familiarization time than full-terms, a finding compatible with those showing that preterms take longer to habituate than full-terms (e.g., Ross, Auld, Tesman, & Nass, 1992; Spungen, Kurtzberg, & Vaughan, 1985). Preterms have also been found to have patterns of attention often associated with slower processing, namely, long looks, slow shift rates (indicative of less active comparison), and more off-task behavior (Rose, Feldman, & Jankowski, 2001; Rose, Feldman, McCarton, & Wolfson, 1988).

There is some indication that a number of the medical risks suffered by preterms have an impact on processing speed (or on measures thought to depend on processing speed). In one study (Rose et al., 1988), the presence of respiratory distress syndrome (RDS) and its severity (as indexed by time on the respirator), were associated with lower novelty scores at 7 months, as was lower gestational age. In another (Rose et al., 2001), more time on the respirator was again associated with lower novelty scores at 7 months, as was being born small-for-gestational age; in addition, a variety of medical risk factors were associated with poorer attention at 5 and 7 months. Moreover, in a study by Ross et al. (1992), preterm infants with subependymal or mild hemorrhage took longer to habituate at 10 months than did full-terms, or preterms without evidence of brain injury.

For the most part, processing speed has been measured only indirectly in infancy, primarily with the paired-comparison and habituation paradigms. In paired-comparison problems, the infant is first familiarized to one or two identical stimuli and then presented, on test, with two stimuli side by side, one new and one old. Familiarization time is preset to an amount judged (on the basis of pretesting) to be long enough for the majority of infants to have encoded the stimulus. The group, as a whole, then generally shows a preference for the novel target on test. Because group novelty scores tend to vary as a function of familiarization time, speed of processing is often inferred from differences in novelty scores. However, this procedure does not provide a direct index of the speed with which the *individual* infant processes the target. Some infants in the group would have had insufficient time to fully encode the target, whereas others would have been forced to continue attending, even though they had finished processing.

Although the habituation paradigm does yield a score that reflects individual differences, it is not clear that these differences are truly, or solely, due to processing speed. In habituation, a target is presented repeatedly until attention declines by some predetermined amount (e.g., half that shown on the first two or three trials). Processing speed is inferred from the number of trials or total looking time taken to reach criterion. However, it is not clear that all the looking time reflects active processing. As a group, infants show novelty scores in the paired-comparison paradigm with less looking than is needed to reach criterion in the habituation paradigm. Thus, it would appear that many infants assimilate the information well before their attention wanes.

It would clearly be desirable to have a more direct measurement of processing speed, not only for testing theoretical formulations about infant cognition but also for gauging individual differences. We have drawn on features of the paired-comparison and habituation paradigms to create such a measure. In doing so, we adapted a method developed by Fantz (1964; see also Roder, Bushnell, & Sasseville, 2000), in which infants are presented with a series of paired stimuli, with one remaining the same from trial to trial and the other changing. In our adaptation, trials terminated when the infant reached a specified criterion of consistent preference for novel stimuli. Because this allowed the same procedure to be used with different age groups, developmental differences in trials to criterion could be assessed using a constant metric. The criterion itself incorporates a test of whether the stimulus has been processed sufficiently for the infant to recognize it as familiar.

Using this new *continuous familiarization* technique, we found an age-related decrease in the number of trials needed by 5-, 7-, and 9-month-olds to process cartoon faces (Rose, Futterweit, & Jankowski, 1999), and by 7- and 12-month-olds to process photos of real faces (Rose, Jankowski, & Feldman, 2002). In both studies, we also found that certain aspects of attention changed developmentally and were related to performance. In particular, with increasing age, infants’ looks got shorter, and they shifted their gaze more often between the paired targets, a behavior presumed to reflect active comparison. Within an age, infants who showed more mature patterns of attention, shorter looks and more shifts, reached criterion faster.

In the present study, we compared performance of preterms on this new task to that of full-terms, using a longitudinal sample assessed at 5, 7, and 12 months. Various aspects of attention during the task were also assessed, compared across groups, and related to speed. Developmental trajectories for speed and attention were examined as well, and those of preterms and full-terms were compared.

Method

Participants

Infants were full-terms and preterms who were participants in a prospective, longitudinal study of cognitive development over the first 3 years of life (5, 7, 12, 24, and 36 months). One of the primary aims of this longitudinal project is to assess the independence, specificity, and stability of performance on measures of memory, speed of information processing, representational competence, and attention. The present study concerns performance on one of the tasks designed to tap speed of information processing, namely, continuous familiarization, at the first three ages.

Infants were recruited from births at two hospitals affiliated with the Albert Einstein College of Medicine. Full-terms were recruited at 5 months through letters sent directly to their parents. The entire sample consisted of 153 full-terms (75 female, 78 male), 144 of whom returned at 7 months (72 female, 72 male), and 126 of whom returned at 12 months (61 female, 65 male). Follow-up rates were thus 94.1% at 7 months and 82.3% at 12 months. Participant loss was due principally to mothers returning to work after maternity leave and finding that their schedules did not permit continued visits. At 5, 7, and 12 months, data were lost due to fussiness/sleepiness for *N*s = 19, 16, and 9, respectively.

Preterms (birthweight < 1,750 g) were recruited from among those born at the same two hospitals and enrolled in an affiliated program that provided comprehensive medical follow-up of low birthweight infants (Low Birthweight Infant Follow-up and Evaluation Program). The entire preterm sample consisted of 50 infants at 5 months (26 female, 24 male), 59 infants at 7 months (28 female, 31 male), and 56 at 12 months (25 female, 31 male). The 59 infants at the 7-month visit included 42 who returned from the 5-month visit plus an additional 17 infants newly recruited at 7 months. Of the 59 preterms seen at 7 months, 94% returned at 12 months. At 5, 7, and 12 months, data were lost due to fussiness/sleepiness for *N*s = 11, 11, and 1, respectively.

Infants were scheduled for one visit at 5 months and two visits at both 7 and 12 months. At each visit, four brief experimental tasks were administered. These tasks took, in toto, about 30 min. The four tasks were carried out in different experimental settings; brief breaks were given between tasks, and longer breaks were given if necessary. At 7 and 12 months, the infant was given an extended break after the four tasks of the first session (for feeding, diapering, play, and/or nap), and then the Bayley Scales of Infant Development were administered.

For full-terms, the initial visits were targeted to the infants' birth dates; second visits were targeted for 2 weeks later. For preterms, initial visits were targeted to the infant's corrected age (i.e., age from expected date of birth). In consequence, the preterms were, on average, 10.4 weeks older in postnatal age (chronological age) than their full-term counterparts. Data for the continuous familiarization task presented here were obtained at the outset of the 5-month visit and at the outset of the first visit at the two older ages. Parents received a stipend of $25 (plus transportation) for each visit.

Background characteristics. Because of the additional recruitment of preterms at 7 months, background data from this age were considered the most representative for the study sample as a whole. The distributions of background factors at this age were presented in detail in Rose et al. (2001).

In brief, full-terms and preterms were similar in all demographic factors: gender, birth order, ethnicity, parental education, and SES. In the total sample, 51% of the infants were male, 36.0% were first born, and 87.6% were either Black or Hispanic. Maternal education averaged 13.2 years (*SD* = 2.2). As determined by the Hollingshead Four-Factor Index of Social Status (Hollingshead, 1975), 31% of the families came from the two lowest social strata (unskilled and semiskilled), 36% from middle social strata (skilled craftsman and clerical workers), and 33% from the two highest strata (business and professional people).

The distributions of background factors for infants seen at 5 and 12 months were similar to those at 7 months. Background characteristics of those seen at one age but not the next (5 but not 7 months or 7 but not 12 months) did not differ from those seen at both ages.

Medical risk characteristics. Full-terms had uneventful pre- and perinatal circumstances, Apgar scores of 9 or 10, birthweights above 2,500 g, and gestational ages of 38–42 weeks.

All the preterms weighed under 1,750 g at birth; 91.9% were VLBW (<1,500 g), and 39.3% were extremely low birth weight (<1,000 g). The average gestational age of these infants at birth was 29.6 weeks (*SD* = 2.9). Apgar scores at 1 and 5 min averaged 5.8 (*SD* = 2.4) and 7.5 (*SD* = 1.4), respectively. With respect to other medical risk factors, 34% were small-for-gestational age, about 50% were diagnosed with RDS, and a similar percentage were diagnosed with intraventricular hemorrhage (Papile, Burstein, Burstein, & Koffler, 1978). However, relatively few, around 12%, had Grade III hemorrhage, and none had Grade IV. Infants spent, on average, 8.6 days (*SD* = 13.9) on the respirator and 20.8 days (*SD* = 23.0) on oxygen; overall, they averaged 53.4 days (*SD* = 23.8) in the hospital. Further details were presented in Rose et al. (2001).

Apparatus and Stimuli

The infants were tested in a three-sided booth constructed from panels of black fabric and measuring 1.2 m on each side and 1.5 m across the front. A display panel, inset in the front of the booth, pivoted back and forth to allow the observer, seated behind it, to position the targets. The observer monitored infant looks through a 7-mm peephole centered between the stimuli. The targets and the infant's face were illuminated by two 40-watt lights, attached to the top of the enclosure and directed downward.

The stimuli consisted of 19 black-and-white matte-finish photographs of the faces of 5- to 9-month-old Caucasian infants; all had neutral facial expressions and were photographed in frontal view. Infants wore a standard smock to eliminate distinctive differences in clothing. Each photograph measured 13 cm × 18 cm and was mounted on a 15-cm × 30-cm black posterboard. Individually, the photos subtended a visual angle of about 16° horizontal × 23° vertical; paired photos were separated by a visual angle of about 23°.

One of the 19 faces served as the familiar target, the other 18 served as novel ones. A single random ordering of the 18 novel targets was used when pairing the familiar face with the novel one. The same ordering was repeated for the second 18 trials (see Rose, Jankowski, & Feldman, 2002, for pictures of the stimuli).[1]

Procedure and Design

Testing took place with the infant seated on the parent's lap, approximately 45 cm from the display panel. On each trial, the familiar target was presented with a different novel one.

Trials began with the first look to either of the paired targets and ended when the infant had accumulated 4 s of looking to the display. The left–right placement of novel and familiar targets was randomized across trials, with the proviso that the novel target not appear on the same side on more than two successive trials. To change stimuli, the experimenter, who was completely hidden from the infant's view, pivoted the stage back 90°, manually removed and inserted the stimulus plaques, and then closed the stage. Each change of stimuli took 3–5 s.

Testing continued until criterion was met. The criterion was met when there were four out of five consecutive trials having a novelty score >55% but less than 100%. That is, for a trial to be included in the criterion run, there had to be some looking directed toward both targets, thus ensuring active comparison between them. In the event that criterion was not met, a maximum of 36 trials was completed.

Looks were monitored on-line and recorded on the computer, which also controlled the timing of trials and determined when the criterion was reached, signaling these events with soft tones. The same tester presented stimuli and recorded looks. To avoid bias, we used several different testers; most were naïve to the hypotheses of the study. Reliability between pairs of observers, which is checked frequently in our laboratory, ranged from *r*s = .92 to .98 (see Rose et al., 2001, for details on reliability).

Measures

There were two measures of processing speed: *trials to criterion*—the number of trials taken to reach criterion, and *total looking to the familiar*—

[1] The familiar face used here was one of three from this earlier study. Because there were no stimulus effects in that study, the present results are unlikely to be specific to the particular face chosen as familiar.

Table 1
Performance on the Continuous Familiarization Task by Birth Status and Age

Age and measure	Full-term *M*	Full-term *SD*	Preterm *M*	Preterm *SD*	Test[a]
5 months	($N = 134$)		($N = 39$)		
Speed of encoding					
Trials to criterion	19.10	11.91	23.38	12.48	1.96*
Total looking to the familiar (s)	29.69	20.97	40.29	23.89	2.69**
Reached criterion (%)	76.12		66.67		1.40
Attention					
Mean look/trial (s)	1.70	0.61	1.67	0.55	0.30
Shift rate/s	0.37	0.19	0.38	0.18	0.14
	($N = 128$)		($N = 48$)		
7 months					
Speed of encoding					
Trials to criterion	15.23	10.55	19.90	10.42	2.62**
Total looking to the familiar (s)	23.49	17.64	31.98	19.33	2.77**
Reached criterion (%)	85.94		83.33		0.19
Attention					
Mean look/trial (s)	1.46	0.46	1.54	0.46	1.14
Shift rate/s	0.47	0.19	0.42	0.15	1.70†
	($N = 117$)		($N = 55$)		
12 months					
Speed of encoding					
Trials to criterion	10.00	6.21	12.89	9.71	2.36*
Total looking to the familiar (s)	15.22	10.62	19.90	16.31	2.25*
Reached criterion (%)	98.29		92.73		3.44†
Attention					
Mean look/trial (s)	1.13	0.29	1.30	0.43	3.17**
Shift rate/s	0.63	0.20	0.53	0.19	3.15**

[a] Means were compared with *t* tests; percentage differences were compared with chi-square.
† $p < .10$. * $p < .05$. ** $p < .01$.

the total amount of time spent looking at the familiar before achieving criterion. Infants not reaching criterion by the 36th trial received a score of 36. (No infant reached criterion on exactly the 36th trial.) Although familiarization time is methodologically dependent on trials to criterion, and the two are highly correlated, $r > .95$, both are retained here for descriptive purposes.

There were two measures of attention: *mean look*—the mean duration of looks on each trial (averaged over trials), and *shift rate*—the number of shifts in gaze from one target to another, expressed as the number of shifts per second.

Results

Effects of Prematurity

The role of birth status. The means and standard deviations of scores are given by birth status in Table 1. Although the groups did not differ significantly in the percentage of infants reaching criterion, at each age full-terms were significantly faster at processing the stimuli than preterms. They took about 20% fewer trials to reach criterion and did so with from 24% to 33% less time looking to the familiar.[2]

For the two attention measures, look duration and shift rate, there were full-term/preterm differences at 12 months: Full-terms had shorter looks and faster shift rates (i.e., more shifts of gaze between the paired targets). These differences were not evident at the two earlier ages.

The role of medical risk. The performance of preterms was related to several medical risk factors, particularly at the two younger ages. At 5 months, the presence of RDS (coded 1 vs. 0), days on respirator, and days on oxygen were each associated with slower processing (i.e., with more trials to criterion and more looking to the familiar), with $|r|$ ranging from .24 to .48. More days on the respirator, more days on oxygen, longer hospital stays, and lower 1- and 5-min Apgar scores were related to poorer attention (i.e., longer looks and fewer shifts), with $|r|$ ranging from .22 to .37.

At 7 months, the presence of RDS continued to relate to slower processing, as did days on the respirator, with $|r|$ ranging from .21 to .30. At this age, lower 1- and 5-min Apgar scores also related to slower processing, with $|r|$ ranging from .29 to .32. None of the medical risk factors were related to attention at 7 months. By 12 months, the associations of medical risk to processing speed and attention had generally diminished, and none were statistically significant.

[2] During the criterion run itself, novelty scores tended to be similar across group and age, averaging about 70%.

Developmental Change

Developmental changes in processing speed and attention were examined in the subset of infants having data at all three ages (N = 119; 89 full-terms and 30 preterms). The means and standard deviations in this subsample were nearly identical to those shown in Table 1 for the full sample.

Changes over age in processing speed were dramatic, with trials to criterion decreasing about 18% from 5 to 7 months and another 34% from 7 to 12 months. The amount of time infants needed to look at the familiar before reaching criterion showed comparable decreases over age. Developmental trajectories were assessed using orthogonal components of trend from a repeated measures 3 (age) × 2 (birth status) analysis of variance (ANOVA), where age was a repeated factor. There was a significant linear decline of trials to criterion over age, $F(1, 117) = 43.24$, $p < .01$. An ANOVA of total looking to the familiar showed a similar significant linear decline over age as well, $F(1, 117) = 41.88$, $p < .01$. There were no significant quadratic trends in either analysis. The effects of birth status mirrored those shown for the entire sample in Table 1, with full-terms reaching criterion in fewer trials and with less familiarization, $F(1, 117) = 6.00$, $p < .05$ and $F(1, 117) = 7.45$, $p < .01$. There were no significant interactions.

The percentage of infants reaching criterion within 36 trials also increased over age. At 5, 7, and 12 months, the percentages for this subsample were 70%, 83% and 97% for preterms, Cochran's $Q(2) = 7.38$, $p < .05$, and 75%, 87%, and 99% for full-terms, Cochran's $Q(2) = 21.36$, $p < .01$. For the groups combined, Cochran's $Q(2) = 28.68$, $p < .01$.

There were also marked developmental changes in attention. For the groups combined, look duration decreased about 10% from 5 to 7 months and another 23% from 7 to 12 months, whereas shift rate increased 22% and 31%, respectively. The ANOVAs showed a significant linear decline in look duration, $F(1, 117) = 59.51$, $p < .01$, and a significant linear increase in shift rate, $F(1, 117) = 61.38$, $p < .01$. There were no quadratic effects, no overall preterm/full-term differences, nor any significant interaction of birth status with age. However, the preterm/full-term differences in look duration and shift rate seen at 12 months in the full sample (see Table 1) were also evident in this longitudinal subsample (significantly so for shift rate, $p < .05$).

Interrelations of Measures

Correlations between measures within each age and group are shown in Table 2. Those relations involving total looking to the familiar target are omitted because this variable uniformly correlated .96 or above with trials to criterion.

Both measures of attention (look duration and shift rate) were related to encoding speed: Infants with shorter looks and more shifts reached criterion in fewer trials. These relations were present at all three ages and similar for the two groups, with absolute values of the correlations ranging from $|r| = .39$ to .65. As expected, the two measures of attention were highly related to one another in both groups, with $|r|$ ranging from .78 to .86.

Stability coefficients—correlations between identical measures across age (not shown in Table 2)—were generally low and nonsignificant, with $|r|$ ranging from .01 to .33; the highest values were generally for look duration in full-terms from both 5–7 months and 7–12 months.

Table 2
Intercorrelations Between Measures by Birth Status and Age

Age and measure	Full-term 1	Full-term 2	Full-term 3	Preterm 1	Preterm 2	Preterm 3
5 months		(N = 134)			(N = 39)	
1. Trials to criterion	—			—		
2. Mean look	.60	—		.51	—	
3. Shift rate	−.56	−.86	—	−.65	−.81	—
7 months		(N = 128)			(N = 48)	
1. Trials to criterion	—			—		
2. Mean look	.58	—		.42	—	
3. Shift rate	−.52	−.86	—	−.40	−.82	—
12 months		(N = 17)			(N = 55)	
1. Trials to criterion	—			—		
2. Mean look	.39	—		.47	—	
3. Shift rate	−.45	−.78	—	−.61	−.85	—

Note. All correlations are significant, $p < .01$.

Discounting Side Bias

It might be argued that infants who took many trials to reach criterion did so because of a strong tendency to look to one side (side bias). Infants have often been found to exhibit such a bias in situations where stimuli are placed side by side. In the present task, given that infants must look to both stimuli on trials in the criterion run, those who had a strong side bias could be at a disadvantage. To determine whether infants who took many trials to reach criterion had such a bias, we counted the number of infants who devoted more than 80% of their total looking time to a single side. At 5, 7, and 12 months, the percentages of infants showing a side bias were similar for preterms and full-terms and were, overall, 10.4% (N = 18), 6.2% (N = 11), and 0.6% (N = 1), respectively. The decline over age was significant, Cochran's $Q(2) = 12.09$, $p = .002$, for the subset of infants having data at all three ages.

Given that side bias was not common and did not differ for preterms and full-terms, it was unlikely to be responsible for the birth status effects found here. To ensure that developmental findings (and cross-age correlations) were not distorted by the change in lateral bias over age, we re-ran these analyses, excluding the data from infants considered to have a moderately strong lateral bias (80% or more looking to one side) at a given age: Results remained unchanged. Overall then, neither developmental nor preterm/full-term differences could be attributed to lateral bias.

Discussion

The results of this study indicate that preterms are markedly slower at processing information than full-terms. The difference between groups was initially detected at 5 months and persisted at 7 and 12 months. Here, for the first time, such preterm/full-term differences are shown with a direct measure of speed. Using a continuous familiarization task, we presented infants with a series of paired faces, one that remained the same from trial to trial and one that changed. Trials continued until a criterion of consistent preference for the novel was reached. Preterms took about 20%

more trials to reach criterion and needed about 30% more time than full-terms to study the familiar face before they could reliably recognize it. The preterm/full-term differences were similar at all three ages. Thus, there was no evidence that the gap in performance narrowed with age or that the preterms caught up. Preterms also showed more immature patterns of attention at 1 year, that is, longer looks and fewer shifts of gaze, consistent with earlier findings in this cohort (Rose et al., 2001). Within the preterm group, several pre- and perinatal medical risk factors—particularly RDS and indirect indices of hypoxic/ischemic events (time on respirator, time on supplemental oxygen)—were associated with slower processing and more immature patterns of attention at 5 and 7 months.

It should be noted that preterm/full-term differences found here were not found in an earlier study (Rose, Feldman, Jankowski, & Caro, 2002) in which processing speed was assessed with the visual expectation paradigm (VExP; Haith et al., 1993). In that paradigm, the latency of eye movements are recorded as the infant watches a series of pictures appearing on a video monitor in either a random fashion (baseline trials) or in a predictable pattern (right–right–left). Although reaction times to stimulus onset were faster for predictable than random sequences, and declined over age, there were no preterm/full-term differences.

This apparent discrepancy regarding preterm/full-term differences in processing speed is probably a function of the different types of speed assessed in the two tasks (see Colombo, 1993; Rose & Tamis-LeMonda, 1999). In the VExP, a simple RT task, infants need only detect stimulus onset and execute a motor response. By contrast, in the present task, infants must encode the stimuli and continually compare one to another.

The differences between groups on these two infant speed tasks have interesting parallels in later childhood. When asked to perform a simple RT task, in which they were required only to detect a single visual stimulus and to give a simple motor response (lift a finger), preterms at 11 years were no slower than full-terms of the same age (Rose & Feldman, 1996). But when the stimulus appeared in one of several locations, and they had to make a choice about where to respond, the preterms were slower. Thus, preterms are slower than full-terms only when the processing involved is cognitively effortful, not when simply responding to the presence of a target.

The results from the present study are also consonant with data on preterm/full-term differences in infant recognition memory (Rose et al., 1988; Rose, Feldman, Wallace, & McCarton, 1989; Sigman & Parmelee, 1974) and with studies where it has been shown that preterm infants need more time than full-terms to encode a stimulus well enough to recognize it (Rose, 1980, 1983). In fact, this poorer visual recognition memory on the part of preterms was found in this cohort as well (Rose et al., 2001). It appears that although preterms are as quick as full-terms to orient to a change in their environment, they are slower at encoding what they see.

The detrimental effect here of RDS (which mignt serve as a marker for perinatal hypoxic-ischemic events) on speed of infant information processing is consistent with earlier data showing that these same medical risk factors adversely affect visual recognition memory in infancy (Rose et al., 1988, 2001) and later childhood (Rose & Feldman, 1996). Considering that individual differences in processing speed are thought to underlie differences in recognition memory, it is not surprising to find that both processing speed and visual recognition memory are vulnerable to the same perinatal risk factors. There is evidence both that recognition memory is mediated by the hippocampus (McKee & Squire, 1993; Nelson, 1995; Reed & Squire, 1997) and that hypoxic-ischemic events selectively damage the hippocampus (e.g., Davis, Tribuna, Pulsinelli, & Volpe, 1986; Volpe, 1995). Our findings raise the possibility that these perinatal insults affect areas of the hippocampus important to the encoding phase of recognition memory.

Although preterms are slower than their full-term counterparts, the two groups were similar in three respects. First, both groups exhibited similar patterns and magnitudes of developmental change in processing speed, with trials to criterion dropping 48% for full-terms over the 7-month interval from 5 to 12 months, and 45% for preterms. For processing speed, the rate of change in full-terms was comparable with that found in two earlier cross-sectional studies using this new procedure. In one, in which the stimuli were cartoon faces, improvement was found over three ages—5, 7, and 9 months (Rose et al., 1999). In the other, in which the stimuli were the same as those used here, improvement was found from 7 to 12 months (Rose et al., 2002). The results from this longitudinal sample confirm these earlier findings and indicate that the pattern of change seen cross-sectionally reflects actual developmental trends.

Second, developmental changes in attention were also similar for preterms and full-terms. Mean look duration decreased by 34% for full-terms and 33% for preterms over the period from 5 to 12 months, whereas shift rates increased by 37% and 40% for full-terms and preterms, respectively. These results are consistent with findings elsewhere (Axia, Bonichini, & Benini, 1999; Colombo & Mitchell, 1990; Colombo, Mitchell, & Horowitz, 1988; Rose et al., 1999; Ruff, 1975) and with earlier findings from this same cohort (Rose et al., 2001).

Third, the relations between attention and speed were similar for preterms and full-terms. For both groups, faster processing was associated with more efficient patterns of attention, as indicated by shorter looks and more shifts (with $|r| = .39$ to .65). To the extent that speed underlies visual recognition memory, these relations are consistent with findings reported earlier from this cohort on the relation between attention and visual recognition memory (Rose et al., 2001).

Although the factors underlying the relation between attention and processing speed are unknown, infants' ability to disengage attention may be implicated. Infants often have difficulty turning their attention away from one target when a new one appears in the periphery (e.g., Hood, 1995; Hood & Atkinson, 1993; Hood, Atkinson, & Braddick, 1998; Johnson, Posner, & Rothbart, 1991). Recently, it has been found that *long-lookers* (infants whose peak and mean looks are characteristically long) disengage more slowly than *short-lookers* when two targets compete for their attention (Frick, Colombo, & Saxon, 1999). Infants who are better at unlocking their gaze would be able to redirect subsequent looks to different regions of the stimulus and thereby process it faster.

A question can be raised about the basis for the persistence of slower processing speed in preterms at 12 months, given that speed was no longer related to biomedical risk factors examined here. First, it should be noted that hypoxic-ischemic insult was not measured directly. If it had been, then such an insult might have been found associated with outcome even at 1 year. Second,

factors other than those studied here might also contribute to the poorer performance of preterms. One such factor, for example, is transient hypothyroxinemia of prematurity, which was found to be associated with poorer mental functioning at 2 years, even with multiple other pre- and perinatal risk factors controlled (Reuss, Paneth, Pinto-Martin, Lorenz, & Susser, 1996). Another such factor is inadequate docosahexaenoic acid, a long-chain polyunsaturated fatty acid that accumulates in the brain and retina, especially during the last trimester of pregnancy and the early postnatal months. Infants born prematurely are generally deprived of this essential fatty acid, which has been directly linked to cognitive development, visual attention, and visual recognition memory (Carlson & Werkman, 1996; O'Connor et al., 2001). Finally, it is possible that premature birth itself, independent of any associated medical conditions, may play a part, by virtue of the impact of the extrauterine environment on immature sensory systems.

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