Pathways From Prematurity and Infant Abilities to Later Cognition

Susan A. Rose
Albert Einstein College of Medicine/Children’s Hospital at Montefiore

Judith F. Feldman
Albert Einstein College of Medicine/Children’s Hospital at Montefiore

Jeffery J. Jankowski
Queensborough Community College/CUNY and Albert Einstein College of Medicine/Children’s Hospital at Montefiore

Ronan Van Rossem
Ghent University

This study examined the relation of information processing in 7-month-old preterms (<1750 g at birth) and full-terms to Bayley Mental Development Indexes (MDIs) at 2 and 3 years. The infant measures were drawn from four cognitive domains: attention, speed, memory, and representational competence. Structural equation modeling showed that these measures of infant information processing mediated the effects of prematurity, and that there was a cascade of effects, with infant processing speed influencing memory and representational competence, which in turn influenced later MDI. This study shows that infant information processing mediates the effect of prematurity on later cognition, and delineates pathways whereby infant abilities relate to one another and to later outcome.

Numerous studies have shown that prematurity often has a negative impact on cognitive outcome. The results are fairly consistent, showing a broad spectrum of intellectual handicaps (Aylward, 2002). These include lower IQ, lags in language development, and a relatively high incidence of learning disabilities and school failure (e.g., Allen, 2002; Amiel-Tison, Allen, Lebrun, & Rogowski, 2002; Aylward, 2002; Bhutta, Cleves, Casey, Cradock, & Anand, 2002; Johnson & Breslau, 2000; McCormick, Brooks-Gunn, Workman-Daniels, & Peckham, 1992; Pinto-Martin et al., 2004; Rickards et al., 1993; Saigal, Hoult, & Streiner, 2000; Scottish Low Birthweight Study Group, 1992a, 1992b; Taylor, Klein, & Minich, 2000; Wolke & Meyer, 1999). While the degree of relative deficit in IQ varies, most studies report that, even with socioeconomic background controlled, the average IQ of preterms falls 5–15 points below the average IQ of full-term groups. Low-birth-weight children also face elevated risks of grade retention, with about half requiring special educational assistance at some point in their school career (Aylward, 2002).

Deficits in Specific Cognitive Abilities: Childhood

One approach to understanding the origins and nature of these poorer cognitive outcomes in childhood and adolescence for children born preterm is to identify the specific abilities that underlie them. A number of recent studies have begun to pinpoint such deficits among children born preterm. In our own laboratory (Rose & Feldman, 1995, 1996, 1997), we found deficits in several specific abilities at 11 years in a longitudinal cohort comprised of very low birth weight (VLBW) preterm and full-term children who had been followed prospectively from infancy. At 11 years, specific abilities were assessed with two batteries: (1) the Specific Cognitive Abilities test (SCA; DeFries & Plomin, 1985), a paper-and-pencil battery assessing memory, perceptual speed, verbal ability, and spatial ability, and (2) the Cognitive Abilities Test (CAT; Detterman, 1988), a computerized battery based on classical experimental paradigms that emphasize assessments of speed and memory.

The preterms scored significantly lower than full-terms on all four specific abilities of the SCA and on many of the speed and memory measures of the...
CAT. These functional deficits are compatible with the results of recent MRI studies, which have revealed a broad range of structural brain abnormalities associated with prematurity, including ventricular enlargement, white matter damage, thinning of the corpus callosum, and delayed myelination (Cooke & Abernethy, 1999; Huppi et al., 1996; Olsen et al., 1998; Stewart et al., 1999). Even when total brain volume is controlled, preterms have reduced cerebellar volume (Owen, Evans, & Petrides, 1996), smaller hippocampi (De Luca et al., 2003; Owen et al., 1996), and smaller basal ganglia, amygdala, and corpus callosum (De Luca et al., 2003). Some of these brain regions are the very ones thought to underlie many of the deficits we have found in specific cognitive abilities.

Our findings of memory deficits in school-aged preterms have recently been corroborated in at least three studies (Curtis, Lindeke, Georgieff, & Nelson, 2002; Isaacs et al., 2000; Luciana, Lindeke, Georgieff, Mills, & Nelson, 1999), one of which linked these deficits to reduced hippocampal volume (Isaacs et al., 2000). Other studies have found impairments in attention, especially among extremely low birth weight children (Hack & Taylor, 2000; Taylor, Hack, & Klein, 1998), and deficits in executive functioning (Anderson, Doyle, & Group, 2004; Curtis et al., 2002; Luciana et al., 1999).

Role of Specific Abilities in Accounting for Preterm/Full-Term Differences: Childhood

Two recent studies with school-aged children and adolescents have explored the import of deficits in specific abilities for the broader intellectual deficits commonly found in preterms. In one study, the 11-year measures of speed and memory from the CAT and SCA were found to account for most of the 10-point difference in the Wechsler Intelligence Scale for Children–Revised (WISC–R) IQ that existed between preterms and full-terms at that age (Rose & Feldman, 1997). In the other, specific abilities assessed at 11 years mediated preterms’ achievement, with perceptual planning being more important for mathematics, and verbal learning and working memory being more important for reading (Taylor, Burant, Holding, Klein, & Hack, 2002). These findings suggest that deficits in specific abilities may explain the more general cognitive deficits frequently found among preterms.

This Study: Infant Origins of Childhood Cognition

This study is concerned with whether the origins of later deficits in broad aspects of cognition, such as IQ, can be traced to infancy. It takes as its point of departure findings pinpointing relative deficits among preterms, in infancy itself, on some of the specific abilities that account for preterm/full-term differences in later IQ and achievement. These include, most notably, processing speed and memory, although other specific infant abilities that may play a role in later cognition have also been identified, such as attention and cross-modal transfer. Some of these infant abilities have shown relations with later IQ, achievement, and language (for overviews, see McCall & Carriger, 1993; Rose & Tamis-Lemonda, 1999) and some have even shown specific cross-age continuity, with the infant measures having at least modest positive correlations with their childhood instantiations (Rose, Feldman, Futterweit, & Jankowski, 1997, 1988).

What has not yet been demonstrated, however, is that preterm/full-term differences in infant abilities account for any of the general cognitive deficits seen at later ages. This is one of the principal aims of the present study, which also examines the theoretical pathways relating infant abilities to later cognition. If indeed individual differences in these abilities are maintained over age, it is anticipated that early abilities will predict later ones. Such findings would have implications for the identification of the roots of later cognition and for the early identification of children at risk.

The aims of this study are thus twofold, (a) to determine the extent to which specific cognitive abilities from infancy mediate the relation of prematurity to later cognition, and (b) to learn more about infant cognition by modeling the relation of specific abilities to one another and the paths by which they influence later outcome.

These issues were examined using data collected as part of a longitudinal study of infant cognition. For purposes of this study, cognitive outcome was represented by mental development, as assessed at 2 and 3 years with the Bayley Scales of Infant Development (Bayley, 1993) and reflected in the Mental Development Index (MDI). Measures of infant information processing, obtained at 7 months, were drawn from four cognitive domains: memory, attention, processing speed, and representational skill. These four domains were selected because they include elementary cognitive processes thought to be fundamental components or underpinnings of cognition and achievement in older children (Bornstein & Sigman, 1986; Colombo, 1993; Rose & Tamis-Lemonda, 1999).

The first domain, memory, is vital for accruing knowledge (Bauer, Wenner, Dropik, & Wewerka, 2000;
Nelson, 1995). Memory, as a domain, is multifaceted, with divisions frequently drawn between short- and long-term memory and, within the latter, between declarative and procedural memory (Squire, 1987). Procedural memory largely refers to retention of learned skills; it is not accessible to conscious recollection and is not affected by amnesia. Declarative memory, by contrast, is directly accessible to consciousness, involves the recollection of facts and events, and is impaired by amnesia. The aspect of memory considered here, visual recognition, is one of the earliest emerging forms of declarative memory. Recognition involves matching a current perceptual experience to one that has occurred earlier (Brown & Aggleton, 2001).

The second domain, processing speed, is often considered to be one of the cornerstones of intelligence (Detterman, 1987; Jensen, 1992; Vernon, 1987), and has been found to be the central limiting factor in many other areas of cognition assessed at older ages (Hale, 1990; Kail, 1991). The aspect of speed considered here, encoding speed, as assessed by a measure newly developed for this project, captures the rapidity of assimilating information (Rose, Feldman, & Jankowski, 2002, 2003; Rose, Feldman, Jankowski, & Caro, 2002; Rose, Futterweit, & Jankowski, 1999; Rose, Jankowski, & Feldman, 2002).

The third domain, attention, is also widely acknowledged as central to an understanding of cognition (Mirskey, 1996; Posner & Petersen, 1990; Posner & Raichle, 1994; Ruff & Rothbart, 1996). One of the most influential formulations of attention, that of Posner, includes three processes: alerting, orienting, and executive control (Posner & Petersen, 1990; Posner & Raichle, 1994). The orienting function, sometimes referred to as “selective attention” (Swanson et al., 1998), involves the capacity to disengage the focus of attention, shift focus, and then reengage attention. The two aspects of attention included in this study, look duration and shift rate, would appear to capture aspects of this function, with short looks reflecting better facility at disengaging (Colombo, 1993; Colombo, Mitchell, Coldren, & Freeseman, 1991; Freeseman, Colombo, & Coldren, 1993; Frick, Colombo, & Saxon, 1999; Jacobson, Jacobson, Sokol, Martier, & Ager, 1993), and higher shift rates reflecting, in addition, more comparison behavior (Rose, Feldman, & Jankowski, 2001a; Rose, Feldman, McCarton, & Wolfson, 1988; Ruff, 1975). Orienting, or selective attention, is present by 6–9 months in response to exogenous stimuli; voluntary or endogenous control of orienting, which is thought to involve different neural circuits, continues to develop through adolescence (Colombo, 2001; Posner & Raichle, 1994).

The fourth domain, representational competence, concerns the ability to create a mental image (or abstraction) of an unseen object or event and use it flexibly. The aspect considered here, tactual–visual cross-modal transfer, involves extracting information about shape from one modality and applying it to another (Rose & Feldman, 1995; Rose et al., 1997; Rose, Feldman, & Wallace, 1988). The infant must construct an image of what a three-dimensional object would look like based on tactual experience alone.

Structural equation modeling. Structural equation modeling (SEM) was used to test three theoretical models of how information processing in these four domains, as assessed at 7 months, might mediate the relation of prematurity to later cognition, as indexed by the Bayley MDI at 2 and 3 years.

These models incorporate three theoretical propositions: (a) that infant information processing mediates, at least in part, the effect of prematurity on later cognition; (b) that there are direct pathways from all information processing measures to later cognition; and (c) there may be indirect pathways as well, with a cascade of effects linking attention and speed to other specific abilities, such as memory and representational competence.

We posited direct links of speed and memory to later cognition, based on theoretical considerations (Gathercole & Pickering, 2000; Heitz, Unsworth, & Engle, 2005; Jensen, 1992; Salthouse, 1996) and our own findings that, when assessed at 11 years, these two aspects of cognition accounted for much of the preterm/full-term difference in IQ (Rose & Feldman, 1997). Additionally, as noted above, there is empirical work linking infant memory (Rose & Feldman, 1995, 1997; Thompson, Fagan, & Fulker, 1991), representational competence (Bornstein & Sigman, 1986; Rose & Feldman, 1995, 1997), and attention (Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004; Sigman, Cohen, Beckwith, Asarnow, & Parmelee, 1991) to later MDI and IQ.

Several lines of evidence also led us to consider the possibility that attention and speed might have indirect rather than direct effects. First, in work with school-aged children, Fry and Hale (1996) considered speed to be a more elementary process than working memory, and found a cascade of effects with processing speed influencing working memory, which in turn influenced intelligence. Second, we found that, in infancy, attention and processing speed independently predicted visual recognition memory at each of three ages, namely, 5, 7, and 12 months (Rose et al., 2003). Third, we assume that the causal arrow goes from attention and speed to visual recognition memory because manipulations that
affect attention (Jankowski, Rose, & Feldman, 2001) and speed (Richards, 1997) influence visual recognition memory.

To represent these theoretical propositions, all models included (a) direct pathways from birth status to constructs representing the four infant measures and to MDI, and (b) direct pathways from visual recognition memory and representational competence to MDI. The three models differed in whether the pathways from attention and speed to MDI were direct or indirect.

Model 1: This model is based on the assumption that attention and speed make both direct and indirect contributions to later MDI, with the indirect paths going through visual recognition memory and representational competence. In this model, and the two below, there are also direct paths from birth status to all variables and direct paths from visual recognition memory and representational competence to MDI.

Model 2: This model is based on the assumption that attention and speed make only an indirect contribution to later MDI, going through visual recognition memory and representational competence, but have no direct contribution (see Figure 1).

Model 3: This model is based on the assumption that attention and speed make only a direct contribution to MDI.

Methods

Participants

Participants were full-term and preterm infants who were enrolled in a prospective, longitudinal study of cognitive development. This report concerns performance on several tasks tapping attention, speed, memory, and representational competence given at 7 months and outcome at 2 and 3 years, as assessed with the Bayley MDI. The institutional review board approved the protocol and signed consent was obtained at each visit from parents, who received a stipend of 25 dollars (plus transportation costs) for each visit.

Infants were recruited from births at two hospitals affiliated with the Albert Einstein College of Medicine. At 7 months there was a total of 203 children (N = 144 full-terms and N = 59 preterms). Of these, 173 children returned at 2 years (119 full-terms and 54 preterms), representing 85.2% of the original cohort, and 160 children returned at 3 years (110 full-terms and 50 preterms), representing 78.8% of the original cohort. Subject loss was principally due to mothers returning to work after maternity leave and the attendant scheduling difficulties.

Two-year Bayley scores were obtained for 162 children, and 3-year Bayley scores were available for 156 children, including 9 children not assessed at 2 years. Of those returning at 2 years, Bayley scores were not obtained for 11 full-terms, either because of serious neurological problems that had developed in the interim (N = 3) or because of parental time constraints (N = 8). Of those returning at 3 years, Bayley scores were not obtained for 4 full-terms, all due to parental time constraints. Bayley scores were obtained on all preterms who returned at 2 and 3 years.

Infants were scheduled for two visits at 7 months. For preterms, visits were targeted to the infant’s corrected age (i.e., age from expected date of birth). They were, on average, 10.4 weeks older in postnatal age (chronological age) than the full-terms. Second visits for both groups were targeted for 2 weeks after the first.

Background characteristics. Full-terms and preterms were similar in all demographic factors: gender, birth order, ethnicity, parental education, and socioeconomic status (SES). Overall, 51.0% of the infants were male, 36.0% were first born, and 87.6% were either Black or Hispanic, with the rest being Caucasian. Maternal education averaged 13.2 years (SD = 2.2); the sample was about evenly distributed across social strata, as determined by the Hollingshead Four-Factor Index of Social Status (Hollingshead, 1975).

Full-terms all had birth weights above 2,500 g, gestational ages of 38–42 weeks, and uneventful preand perinatal courses. Preterms (all of whom weighed <1,750 g at birth) had an average birth weight of 1,107.9 g (SD = 282.6) and an average gestational age of 29.6 weeks (SD = 2.9). None of the infants had any obvious congenital, neurological, or physical abnormalities at birth (Rose et al., 2001a).

Procedure

The tasks used here are a subset of a larger battery and were chosen if they yielded measures that related either to birth status or MDI. The measures included were drawn from two tasks assessing memory (Rose and Fagan tasks of visual recognition), one assessing encoding speed (continuous familiarization), and one assessing representational competence (cross-modal transfer). Attention (look duration and shift rate) was assessed by measures culled from each of these tasks. (Measures excluded, because they did not relate either to birth status or MDI, were those from tasks assessing memory span [Rose, Feldman, & Jankowski, 2001b], delayed recognition [Rose, Feldman, & Jankowski, 2004],...
and visual expectations (Rose et al., 2002; Rose et al., 2004).

Infant Tasks and Measures

**Memory.** There were two tasks assessing recognition memory. Both used the paired-comparison procedure, in which infants are familiarized to one stimulus and tested by pairing a novel stimulus with the familiar one. Recognition memory was measured by the novelty score, the percentage of total looking time on test spent looking at the novel stimulus.

The “Rose,” developed in our own laboratory, consisted of nine problems: five using black-and-white photographs of faces and four using colorful abstract patterns. During familiarization, two identical stimuli were displayed until the infant accumulated a fixed amount of study time: 20 s for faces and 5 s for patterns. On test, the familiar stimulus was paired with a novel one for 10 s. A composite was created by averaging novelty scores across the nine problems (Rose et al., 2001a).

The “Fagan” (Fagan & Shepard, 1989) consisted of 10 problems, all using photographs of faces. In this task, sometimes a single stimulus was presented on familiarization instead of two identical ones (as in the Rose) and sometimes the familiarization phase was omitted altogether because the target had appeared in a prior problem. Additionally, on test, the novel target was sometimes a variant of the old one, with a change in pose or orientation, rather than a completely new one, as was invariably the case in the Rose. A composite was created by averaging novelty scores over the 10 problems.

**Speed.** Encoding speed, the aspect of speed considered here, was assessed with the “continuous familiarization” task. In this task, modeled after Fantz (1964), infants were presented with a series of paired stimuli (in this case, photographs of faces), one that remained the same from trial to trial and one that changed. Testing continued until infants showed a consistent preference for the new one, defined as four out of five consecutive trials having a novelty score > 55%, but < 100% (thus ensuring at least some looking to each target in the criterion run), or for the maximum of 36 trials. 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. Encoding speed was measured by Trials to Criterion, the trial on which the criterion was met; if the criterion was not met, the infant was assigned a score of 36 (Rose, Feldman, & Jankowski, 2002).

**Representational competence.** Representational competence was assessed with a task of cross-modal transfer, using an adaptation of the paired-comparison procedure in which stimuli were presented for familiarization in the tactual mode and for test in the visual mode. There were 11 such problems. The stimuli were pairs of three-dimensional geometric forms; members of a pair differed primarily in shape. Here, during the familiarization phase (40 s), one stimulus from a pair was placed in one of the infant’s hands for tactual exploration. The experimenter cupped his/her hands around the infant’s hand to shield the object from view. If the infant did not spontaneously manipulate the object, the experimenter moved it within the infant’s hand from time to time. During test (20 s), paired stimuli were presented on a tray, and moved slowly toward and away from the infant (but out of reach). Cross-modal transfer was measured by the novelty score and a composite created by averaging over problems. For further details about this type of task, see Rose, Gottfried, and Bridger (1978).

**Attention.** Attention was assessed with measures of look duration and shift rate. Look duration was measured as the mean length of look (in seconds). Six measures of look duration were drawn from four tasks: two from the Rose (familiarization and test), two from the Fagan (familiarization and test), one from cross-modal transfer (test), and one from continuous familiarization (all trials). In each case, mean look durations were averaged over all problems in a task (or all trials, in the continuous familiarization task). In view of differing familiarization times, the various measures of mean look duration were standardized before being averaged to form a composite.

Shift rate was defined as the number of shifts of gaze between paired targets per second. Four measures of shift rate were drawn from three tasks: two from the “Rose” (familiarization and test), one from cross-modal transfer (test), and one from continuous familiarization (all trials). Mean rates were derived for each task and then averaged to form a composite.

Outcome Task in Early Childhood

The Bayley Scales of Infant Development (Bayley, 1993) were administered at 2 and 3 years. These scales yield an MDI that has a mean of 100 and a standard deviation (SD) of 15.

Data Analytic Strategy

Mean differences between infants with and without follow-up data, and between preterms and full-
terms, were evaluated for all measures with $t$ tests; examination of the univariate distributions, separately by group, indicated one outlying value (defined as 2.5 SD from the mean), which was deleted. To assess gender differences and gender by birth status interactions, 2 (term/preterm) × 2 (gender) analysis of variances (ANOVAs) were conducted separately for each measure.

**Bivariate relations.** Bivariate relations were assessed separately for the two groups, using Pearson product–moment correlations. Outlying values (2.5 SD from the regression line) were eliminated. To determine whether the groups could be combined for further analyses, the matrices of correlations for preterms and full-terms were compared with LISREL (Version 8.54) (Jöreskog & Sörbom, 2003) using the SEM procedure described by Green (1992). If the matrices are equivalent, this procedure will yield a nonsignificant $\chi^2$, a goodness-of-fit index (GFI) of 0.90 or higher, and a root mean square residual (RMSR) of 0.05 or less.

**Path models.** SEMs of the pathways by which infant information processing mediates the relation of birth status to mental development were tested with LISREL using maximum likelihood estimation. Analyses were performed separately for the 2- and 3-year outcomes. In each case, only children having MDI data at the relevant follow-up age were included. Data missing on 7-month measures (2.9% of the data points) were imputed using the expected maximum (EM) algorithm in PRELIS. Separate models were estimated to avoid imputing missing endpoint data for any child. Model fit was determined by a nonsignificant normal theory weighted least squares $\chi^2$, and supplemented with two indexes that have been found to be sensitive to model specification without being overly sensitive to sample size: the root mean square error of approximation (RMSEA) and the root mean square residual (RMR). For both, values less that .05 constitute a good fit; additionally, values of the RMSEA less than .08 constitute an acceptable fit (Brown & Cudeck, 1993).

All models included six latent variables: (1) birth status, indicated by a single observed variable, coded 1 for children born at term and 0 for children born prematurely, (2) attention, indicated by two observed variables, namely, composite scores for mean look duration and shift rate, (3) speed, indicated by a single observed variable, trials to criterion from the continuous familiarization task, (4) visual recognition memory, indicated by two observed variables, namely, novelty scores from the Rose and Fagan, (5) representational competence, indicated by a single observed variable, namely, the novelty score from the cross-modal task, and (6) mental development, indicated by Bayley MDI at 2 or 3 years.

As noted earlier, three models were estimated for each MDI outcome. Model 1 assumed direct effects of all four 7-month indicators on MDI, as well as indirect effects of speed and attention on MDI through visual recognition memory and representational competence. Model 2 assumed that speed and attention had only indirect effects on MDI, while Model 3 assumed that all effects were direct and none indirect. As our prime interest was in the strength of the various effects, all models were estimated from the correlation matrix for the observed variables.

In all models, the latent variables for attention and speed were allowed to correlate, as preliminary results indicated that not all of the observed relation between attention and speed was due to prematurity. Additionally, the paths between the latent and observed variables were set to equality for the two indicators of attention and the two indicators of visual recognition memory. In order to have higher scores reflect better performance on all measures, the directionality of two variables (mean look duration and trials to criterion) was reversed.

**Results**

**Preliminary Considerations**

Background characteristics were similar for children who did and did not provide follow-up data at 2 and/or 3 years and, with one exception, so were scores on 7-month infant measures. The exception was cross-modal transfer, where scores were somewhat higher for children with 2-year Bayley than for those without it ($M = 48.9$ and 46.9, respectively; $SD = 5.4$ and 4.3; $t(196) = 2.07$, $p < .05$). At 3 years, this was not the case.

Two-way ANOVAs (gender and birth status) indicated that, with one exception, there were no main effects of gender. The exception was 2-year MDI, which was higher for females ($M = 87.97$; $SD = 16.12$) than for males ($M = 81.40$; $SD = 14.74$), $F(1, 158) = 6.50$, $p < .05$. Again, this difference was not present at 3 years. Given that there were no interactions of gender with birth status, and no main effects of gender on infant measures, gender was dropped from further consideration.

**Descriptive Statistics and Correlational Analyses**

Descriptive statistics are given for all measures in Table 1, along with preterm/full-term differences. In
infancy, preterms showed poorer attention and memory, and slower encoding speed. (For a fuller discussion of these birth status differences, see Rose et al., 2001a; Rose, Feldman, & Jankowski, 2002; Rose et al., 1988; Rose, Feldman, Wallace, & McCarton, 1989.) At 2 and 3 years, while both groups had mean MDIs below that of the standardization sample (a finding consistent with their relatively low SES status), the mean MDI of the preterms was significantly lower than that of the full-terms.

A comparison of the correlation matrices for preterms and full-terms yielded a non-significant $\chi^2$, indicating that the two sets of correlations did not differ. That being the case, correlations for the two groups were combined and birth status partialed to avoid inflation due to mean differences. As can be seen in Table 2, both measures of attention—look duration and shift rate—correlated with trials to criterion (encoding speed). MDI from both ages correlated with speed, recognition memory, and cross-modal transfer.

**Structural Model**

**Two-year outcome.** As can be seen in Table 3, Models 1 and 2, both of which included indirect paths from attention and speed to MDI, fit the data, while Model 3, which included only direct paths, did not.

Because Models 2 and 3 were nested within Model 1, their fit to the data could be compared to that of Model 1, using $\chi^2$ difference tests. The results indi-
cate that the fit of Models 1 and 3 differ significantly, \( \chi^2 (4) = 22.86, p < .01 \), whereas that of Models 1 and 2 do not, \( \chi^2 (2) = 0.43, ns \). As Models 1 and 2 do not differ significantly in fit, the criterion of parsimony would suggest that Model 2 is to be preferred over Model 1 because it includes fewer paths. Model 2 also has the advantage of being in accord with a growing body of evidence indicating a cascade of effects whereby some specific processes affect others, which in turn affect general cognitive ability. As indicated by the structural equation \( R^2 \), Model 2 accounted for 37% of the variance in MDI at 2 years.

The results for Model 2 are depicted in Figure 1. There are three points of interest. First, the relation of birth status to MDI at 2 years was entirely mediated by infant measures: those measures fully accounted for preterm/full-term differences in the 2-year MDI. Second, there were significant pathways from infant memory and representational competence to MDI at 2 years. Third, there was an indirect path from speed to MDI, through both visual recognition memory and representational competence. Thus, for speed (but not attention), there was confirmation of the theoretical cascade of effects in which speed affected memory and representational competence, which in turn affected later general mental ability.

Three-year outcome. For MDI at age 3, Models 1 and 2 again fit the data. As can be seen in Table 3, the fit indexes for 3-year outcome were similar to those found at 2 years. Some of the paths, those to and among the 7-month variables, would, of necessity, be quite similar at the two ages, given the overlap of the samples. However, it is notable that the same pathways are involved in the relations of prematurity and infant information processing to MDI at 3 years as were involved at 2 years (see Figure 1). As before, the fit of Models 1 and 3 differed significantly, \( \chi^2 (4) = 24.47, p < .01 \), whereas that of Models 1 and 2 did not, \( \chi^2 (2) = 0.43, ns \). Model 2 accounted for 24% of the variance in MDI at 3 years.

Discussion

This study is the first to show that infant information processing mediates the effect of prematurity on later cognition and the first to delineate pathways by which infant abilities relate to one another and to later outcome.

With respect to prematurity, the findings indicate that information processing assessed at 7-months fully accounted for the deficits on Bayley MDIs found at both 2 and 3 years. The infant measures were drawn from four cognitive domains: attention, speed, memory, and representational competence. Attention was indexed by look duration and shift rate; speed, by trials to criterion on a new task designed to capture individual differences in encoding speed; memory, by novelty scores from two paired-comparison tasks of visual recognition; and representational competence, by tactual–visual cross-modal transfer. At 7 months, preterm performance was poorer than that of full-terms in the first three domains. The findings of the present study show that preterm deficits in infant information processing have important implications for global cognitive compromise in later childhood.

Theoretically, there is a finite set of simple cognitive processes that constitute the building blocks of more complex abilities (Detterman, 1987). The present results are in line with earlier studies suggesting that a subset of these is responsible for the global cognitive deficits frequently found in preterms. As noted in the introduction, two recent studies showed that specific cognitive abilities could account for more general ones assessed contemporaneously in later childhood. In one, Rose and Feldman (1997)
found that preterm/full-term differences in IQ at 11 years could be explained largely by preterms’ deficits in processing speed and memory. In the other, Taylor et al., (2002) found that the deficits of low–birth-weight children in mathematics and reading at 11 years were mediated by perceptual planning and verbal abilities. The present study extends this work by demonstrating that specific deficits in attention, speed, and memory can be detected within the first year of life, and that these very early deficits are critical to general cognitive compromise at later ages.

Figure 1. Pathways from prematurity and infant information processing at 7 months to mental development at 2 and 3 years (Model 2). Significant paths are indicated by solid lines; non-significant paths by dashed lines. Standardized coefficient are given for significant paths. The curved double-headed arrow indicates significant correlations between latent variables. *p ≤ .05. **p ≤ .01.
With respect to the pathways linking infant information processing to preschool cognition, there appears to be a cascade of effects. In particular, infant abilities that could be thought of as relatively elementary were found to influence those considered more complex, which in turn influenced general cognition. Here, speed, which was assumed to be a fairly elementary component of cognition, influenced the somewhat more complex abilities, memory and representational competence; these in turn influenced Bayley MDI at 2 and 3 years. The assumption of a more fundamental role for speed is supported by two findings. First, the model that eliminated direct pathways from attention and speed to later MDI (Model 2) fit the data just as well as the one that included them (Model 1). Second, the model that contained only direct paths from all four infant abilities to MDI (Model 3) did not fit the data. Thus, indirect paths from speed through the more complex abilities, visual recognition memory and representational competence, were both necessary and sufficient to achieve a good fit to the data. These results are consistent with those of Kail and Hale, who, building upon studies that found processing speed to be the limiting factor for memory, suggested a cascade of effects in which individual differences in processing speed influence memory, which in turn affects general cognitive ability (Hale, 1990; Kail & Salthouse, 1994).

The present results are compatible with those from our earlier longitudinal study of preterms and full-terms, in which speed and memory at 11 years, in addition to mediating the effects of prematurity on 11-year IQ (Rose & Feldman, 1996), were also found to mediate the relation of 7-month visual recognition memory to 11-year IQ (Rose & Feldman, 1995, 1997). Both of these earlier studies assumed that the variance in infant visual recognition memory was influenced, at least in part, by variance in encoding speed, an assumption borne out in the present study. Presumably, it was the variance shared between infant visual recognition memory and 11-year encoding speed that accounted for some of the relation of the infant measure to 11-year IQ. Direct measures of encoding speed were not previously available in infancy (Rose, Feldman, & Jankowski, 2002). Here, encoding speed could be assessed contemporaneously with infant visual recognition memory and the direction of influence modeled in a way consistent with the theoretical cascade from speed to memory (Hale, 1990; Kail & Salthouse, 1994).

The present results are also consistent with earlier findings, from this current cohort, showing that different measures of cognitive performance in infancy reliably form separable and distinguishable constructs (Rose et al., 2004). Here, we carried this work forward, showing that some of these same aspects of infant cognition mediate the effects of prematurity on later mental development.

The approach taken here is a "componential" one, in which more specific or elementary abilities combine to yield more general abilities (Detterman, 1987). This approach contrasts with that where individual differences in IQ and language are attributed to a general factor, such as "g" (Eysenck, 1967; Jensen, 1982, 1987, 1992). The componential approach shares with information processing theories of intelligence the notion of a core set of elementary operations (Sternberg, 1985). It also shares with clinical neuropsychology the notion of modular design of both the brain and its functions (Fodor, 1983; Karmiloff-Smith, 1992), and with classical cognitive psychology the notion of distinct domains of cognitive operations (e.g., memory, attention, reasoning). The present work suggests that this theoretical approach is applicable even in infancy.

There are two potential methodological limitations to the present study. First, the present sample is hospital-based, and thus we cannot be certain how the findings would generalize to a broader population. However, our results are in line with those from regional and population-based studies conducted worldwide in showing cognitive problems in children born preterm (Aylward, 2002; Bhutta et al., 2002; Whitaker, Feldman, Breslau, & Paneth, in press). Second, the relatively high social risk of the sample, which was mostly minority and of relatively low SES, could limit generalizability. However, recent studies of school-aged children have found that the cognitive difficulties of preterms are not restricted to low SES samples (Taylor et al., 2002; Whitfield, Grunua, & Holsti, 1997). Indeed, the cognitive sequelae of prematurity appear to persist, at least throughout the high school years, even among those preterms being raised in privileged communities (Breslau, Paneth, & Lucia, 2004). While the negative effects of prematurity are compounded by social risk (Escalona, 1982), these two factors appear to have an additive rather than an interactive effect on outcome (Breslau et al., 2004; Whitaker et al., in press).

Overall, the results of this study suggest that the specific cognitive deficits underlying later global ones can be pinpointed in infancy and the pathways from infant abilities to later cognition delineated. By implication, measures of infant information processing may hold promise as early assessments of the effects of obstetrical, prenatal, and neonatal interventions.
References


