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A Cognitive Cascade in Infancy: Pathways from Prematurity to Later Mental Development

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Abstract

Using data from a longitudinal study of preterms and full-terms, the present study examined the structure of infant cognition at 12 months, the extent to which five 12-month abilities (attention, speed, recognition, recall, and representational competence) mediated the relation from prematurity to mental development at 2–3 years, and how continuity and change in infant information processing from 7 to 12 months affected later outcome. The results indicated that 12-month measures of infant information processing completely mediated the effect of prematurity on outcome and the infant measures form a 'cognitive cascade,' similar to that seen at 7 months, in which the two more elementary abilities (attention and speed) influenced the more complex ones, which in turn influenced later cognition. Additionally, despite cross-age stability, 7-month assessments contribute to outcome independently of their 12-month counterparts, suggesting that infant abilities undergo important developmental transformations in the second half of the first year of life.

There is a growing effort to understand how specific information processing abilities relate to general intelligence and other aspects of cognition. One approach to this issue is to identify the primary building blocks of intelligence (Detterman, 1987) and to find the pathways that link specific abilities to more general ones (Conway, Cowan, Bunting, Theriault, & Minkoff, 2002; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Such an approach has theoretical value, for understanding the nature and structure of cognition, and practical significance, for uncovering the specific cognitive deficits associated with particular environmental and biological sources risk.

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One group at risk for later cognitive deficits are children born preterm or low birthweight (Aylward, 2002). Such deficits, which generally become evident when the children reach school age, include lower scores on tests of IQ, language, and school achievement (Allen, 2002; Aylward, 2002; Bhutta, Cleves, Casey, Cradock, & Anand, 2002). There is now reason to think that some of these later deficits may have their roots in infancy. First, studies of information processing in the first year of life have found preterms to be slower at encoding information than full-terms, and to have poorer recognition memory, recall memory, and attention (de Haan, Bauer, Georgieff, & Nelson, 2000; Miranda & Fantz, 1974; Rose, 1980, , 1983; Rose, Feldman, & Jankowski, 2001, , 2002, , 2005; Sigman & Parmelee, 1974; Spungen, Kurtzberg, & Vaughan, 1985). Second, the newer infant information processing abilities have been found to predict IQ and language in later childhood and early adolescence (Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004; Dougherty & Haith, 1997; Fagan, 1984; Fagan & Haiken-Vasen, 1997; Fagan & McGrath, 1981; McCall & Carriger, 1993; Rose & Feldman, 1995; Rose, Feldman, & Jankowski, 2003a; Sigman, Cohen, Beckwith, Asarnow, & Parmelee, 1991; Thompson, Fagan, & Fulker, 1991).

These developments make it possible to now consider (a) mapping the structure of infant cognition, and (b) determining the role of infant abilities in the later cognitive deficits often seen in preterm children. Mapping the structure, which parallels the work currently being done with adults and older children (Conway et al., 2002; Miyake et al., 2000), is aimed at elucidating the nature and interrelationships of the primary abilities that form the scaffolding for complex cognitive thought. Determining the role of infant abilities in later cognition, which extends downward work with older children (e.g., Rose et al., 1996; Taylor, Burant, Holding, et al; 2002), is aimed at identifying specific areas of cognitive weakness in risk groups.

We recently proposed a model of infant cognition with two central tenets (Rose, Feldman, Jankowski, & Van Rossem, 2005). First, infant cognition was posited to be characterized by a *cognitive cascade* in which more fundamental or basic abilities underpin more complex ones that, in turn, influence general intelligence. Second, the measures of infant information processing involved were posited to mediate the relation between birth status and later cognition. The model was evaluated with data from a prospective longitudinal study of preterm and full-term infants using a information processing at 7-months and the Bayley Mental Development Index (MDI) from 2 and 3 years. The 7-month measures were drawn from four domains: attention, processing speed, visual recognition memory, and representational competence, with attention and speed considered more elementary than the latter two. Abilities from these particular domains were selected because of their (a) central role in later cognition, (b) demonstrated presence in infancy, (c) sensitivity to cognitive risk, and (d) relation to later intelligence.

Attention and speed were considered more elementary or basic because work with older children and adults show their pivotal role in other aspects of cognition. Attention is thought to act as a 'gatekeeper,' modulating brain activity to control the scope and flow of perception, and access to memory systems for mnemonic encoding (Pessoa, Kastner, & Ungerlieder, 2002) whereas processing speed, a central aspect of 'g' (Jensen, 1987; Vernon, 1987), controls the knowledge accrued per unit of time. Attention and processing speed have both been shown to relate to memory (Rose, Feldman, & Jankowski, 2003b) whereas memory and representational competence, more complex abilities, are related to later IQ and language (Fagan, 1984; Fagan & Haiken-Vasen, 1997; Rose & Feldman, 1995, , 1997; Rose, Feldman, Jankowski, & Van Rossem, 2005; Thompson et al., 1991).

The 7-month data supported both tenets of the model. Using structural equation modeling (SEM) we found, as posited, a cognitive cascade, in which the more elementary infant abilities influenced the more complex ones which, in turn, influenced subsequent MDI. These findings

showed, for the first time, how primary abilities could form the scaffolding for complex thought. The second tenet of the model -- that infant cognition would mediate the relation between birth status and later cognition -- was also supported. In fact, infant cognition mediated the entire relation between birth status and later MDI in the 7-month model.

Because the cognitive abilities involved in this model are known to undergo rapid maturation and change in the latter half of the first year (e.g., Colombo & Cheatham, 2006), it is not at all clear that the structure found at 7 months would endure. For example, it has been suggested that visual recognition memory is more predictive at 7 months than at later ages (McCall and Carriger, 1993). Moreover, this period encompasses a watershed in the development of many of the hippocampal and frontal areas that underlie attention and memory, including substantial increases in neuron size and density in the CA2 and CA3 subfields of the hippocampus (Zaidel, 1999) and development of the dentate gyrus (Nelson, 1995, , 1997).

The primary purpose of the present study is to test the applicability of the 7 months model at the end of this period of rapid change, at 12 months. For this purpose, we will use the same cohort of full-terms and preterms that had been used at 7 months. At 12 months, the assessment battery is broadened to include measures of recall memory, a form of declarative memory that appears to be independent of recognition early in life.

In addition to assessing the fit of the cascade model at 12 months, the present study will also examine the extent to which 12-month measures mediate the effects of their 7-month counterparts on MDI. To the extent the measures show cross-age stability, one generally expects later measures to mediate the effects of earlier ones. However, this may not be as characteristic of development in infancy as one would think. In a review of prediction studies, McCall and Carriger (1993) found that visual recognition memory often predicted IQ more strongly when assessed at 7 months than at later ages. Thus, predictive power of some abilities might be more pronounced early on, when they are still emerging, than later, when they are more established. Additionally, given the relative complexity of some infant abilities, the importance of their component processes may change over time.

Methods

Participants

The original sample for this prospective, longitudinal study included 59 preterm infants and 144 term controls, born between February 1995 and July 1997. Preterm infants were recruited from consecutive births admitted to the neonatal intensive care units of two hospitals affiliated with Albert Einstein College of Medicine. Criteria for study intake were: singleton birth, birthweight <1750 g, and the absence of any obvious congenital, physical, or neurological abnormalities. Term infants were recruited from consecutive births from the same hospitals; criteria for study intake were birthweight >2500 g, gestational age of 38–42 weeks, 5-minute Apgar scores of 9 or 10, and uneventful pre- and perinatal circumstances (Rose et al., 2001a).

For preterms, the return rates at 12, 24, and 36 months were 94.9%, 91.5%, and 84.7% ($N = 56, 54, \text{ and } 50$, of the original 59); for full-terms, the comparable figures for full-terms were 87.5%, 82.6%, and 76.4% ($N = 126, 119, \text{ and } 110$, of the original 144). Subject loss was principally due to mothers returning to work after maternity leave and the attendant scheduling difficulties.

The present report included those children who had infant data at 12 months, $N = 182$. Of these, $N = 167$ had Bayley MDIs at 2 and/or 3 years (with 148 having Bayley scores at both ages, 14 at 2 years only, and 5 at 3 years only). Bayley scores were unavailable for 8 children at 2 years (all full-terms; 5 because of emerging neurological problems, and 3 due to parental time

constraints) and an additional 7 children at 3 years (6 full-terms and 1 preterm; all due to parental time constraints).

Visits of the preterm infants were targeted to 'corrected age,' calculated from expected date of birth, with the result that they were, on average, 10.4 weeks older in postnatal age than the full-term infants. Because of the extensive battery of infant tasks, two visits were scheduled at 12 months, with the second targeted for two weeks after the first.

The institutional review board approved the protocol and signed consent was obtained at each visit from parents, who received a stipend of twenty-five dollars (plus transportation costs) for each visit.

Sample Characteristics—At 12 months (as at intake) the two groups for the longitudinal study were similar in gender, birth order, ethnicity, parental education, and socio-economic status (SES), with 52.7% male, 36.0% first born, and 87.6 % either Black or Hispanic. Maternal education averaged 13.2 years ($SD = 2.2$) and SES, as assessed by the Hollingshead Four-Factor Index of Social Status (Hollingshead, 1975) averaged 32.3 ($SD = 13.9$). Overall, medical and background characteristics are indistinguishable from those seen at 7 months (for further details, see(Rose et al., 2001).

Procedure

A large battery of tasks was administered at 12 months. For the most part, we used the same tasks at 12 months that we had used at 7 months, tailoring some of the time parameters to make the tasks age appropriate. There were two measures of recognition memory (from two visual paired-comparison tasks), two of recall (from elicited imitation and symbolic play), one of encoding speed (continuous familiarization), and one of representational competence (cross-modal transfer). Measures of attention (look duration and shift rate) were culled from several of these tasks. Recall (Bauer, Wenner, Dropik, & Wewerka, 2000; Nelson, 1995), was the only ability not included at the earlier age.

At 2 and 3 years, children were given the Bayley Scales of Mental Development (Bayley, 1993).

Infant Measures

Recognition memory—Recognition memory, one of the earliest emerging forms of explicit memory, was assessed with two visual paired-comparison tasks. In both, infants were familiarized with a stimulus and then tested for recognition by pairing the familiar with a novel target. Recognition memory is typically inferred from differential attention to the two test stimuli and is measured by the *Novelty Score*, the percentage of looking time devoted to the novel target.

One task, the 'Rose,' developed in our own lab, was comprised of 5 face problems (10s familiarization) and 4 pattern problems (3s familiarization). The test periods lasted for 10s (Rose et al., 2001). The other task, the 'Fagan' (Fagan & Sheperd, 1989), comprised of 10 face problems, had a similar format. Composites for each test were created by averaging individual novelty scores.

Moderate test-retest reliabilities have been reported for composites such as these over periods of one week, $r = .40$ and $.51$ (Colombo, Mitchell, & Horowitz, 1988; Rose & Feldman, 1987; Rose, Feldman, & Wallace, 1988)

Recall Memory—Recall memory was assessed with two tasks, elicited imitation and symbolic play. In elicited imitation, the examiner modeled each of three event sequences (e.g.,

place small block on paddle, cover block, shake paddle to create rattle sound) three times in succession; after a 15-min delay, the infant was given the props for each sequence, in turn, to reproduce the sequences (Bauer, 2002; Bauer, Van Abbema, & de Haan, 1999; Bauer, Wiebe, Carver, Waters, & Nelson, 2003). Recall memory, measured by the *Percentage of Target Actions Reproduced* for each event sequence, was averaged over sequences (for further details, see (Rose, Feldman, & Jankowski, 2005).

Reliability estimates are not available for this measure, although short-term stability over a 4-month period in the second year of life has been found, $r = .45$ to $.52$ (Bauer, personnel communication).

The symbolic play task was an adaptation of the free play procedure of Tamis-LeMonda and colleagues ((Damast, Tamis-Lemonda, & Bornstein, 1996; Tamis-LeMonda & Bornstein, 1990). In this adaptation, successively higher levels of symbolic play were elicited by modeling increasingly complex sequences of pretense actions. The infant was encouraged to imitate each sequence (e.g., child feeds the doll and makes eating sounds for the doll) immediately after it was demonstrated. There were 18 levels, with four opportunities to succeed at each; testing terminated when two levels were failed in succession. Recall was measured by the *Highest Level* achieved.

Inter-rater reliability obtained on this task in our lab was $r = .97$. Test-retest reliability is not yet available.

Speed—Encoding speed was assessed with ‘continuous familiarization,’ in which infants were presented with a series of paired photographs of faces, one that remained the same from trial to trial and one that changed. Trials lasted for 4 s and 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 $< 100\%$ (to ensure inspection of both targets), or for the maximum of 36 trials. Encoding speed was measured by *Trials to Criterion*, the number of the trial on which criterion was met (or 36, if criterion was not met, see (Rose, Feldman, & Jankowski, 2002; Rose et al., 2003b; Rose, Feldman, Jankowski, & Caro, 2002; Rose, Futterweit, & Jankowski, 1999; Rose, Jankowski, & Feldman, 2002). Test-retest reliability over a 2-week interval, obtained for a sample of 5-, 7-, and 9-month-olds, was $r = .27$, partialled for age (unpublished data).

Representational Competence—This construct, considered here to refer to the ability to create a mental image (or abstraction) of an *unseen* object or event and use it flexibly. It was assessed with tactual-visual cross-modal transfer, in which information about shape had to be extracted tactually and recognized visually (Rose & Feldman, 1995; Rose, Feldman, Futterweit, & Jankowski, 1997; Rose, Feldman, & Wallace, 1988). In this task, comprised of 11 problems, 3-dimensional forms were presented for familiarization in the tactile mode (20 s). On test, the previously felt object and a new one were presented visually for 20 s. (For further details, see (Rose, Gottfried, & Bridger, 1978). Cross-modal transfer was measured by the *Novelty Score*, the percentage of looking time devoted to the novel target in the visual test phase. A composite was created by averaging over problems.

Although reliability data is unavailable for this measure, modest stability over periods of one month (6 to 7 months and 7 to 8 months) has been found, $r = .25$ and $.41$ (unpublished data).

Attention—Two measures, look duration and shift rate, were used to assess attention. They are thought to reflect orienting (Mirsky, 1996; Posner & Petersen, 1990; Posner & Raichle, 1994) or selective attention (Swanson et al., 1998), where the focus of attention must be repeatedly engaged, disengaged, shifted, and then re-engaged. Shorter looks are thought to

reflect better facility at disengaging attention (Colombo, 1993; Colombo, Mitchell, Coldren, & Freese, 1991; Freese, Colombo, & Coldren, 1993; Frick, Colombo, & Saxon, 1999; Jacobson, Jacobson, Sokol, Martier, & Ager, 1993) and higher shift rates are thought to reflect, in addition, more comparison behavior (Rose et al., 2001; Rose, Feldman, McCarton, & Wolfson, 1988; Ruff, 1975). There were six measures of *mean look duration (s)*, gleaned 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), the six measures were then standardized, and then averaged to form a composite.

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

Although test-retest reliability is not available for these measures, for the scores in the present study, internal consistency coefficients (another method of estimating reliability) were high: $\alpha = .76$ (look duration) and $\alpha = .70$ (shift rate).

Outcome Measures in Early Childhood

The *Bayley Scales of Infant Development* (Bayley, 1993) were administered at two and three years. These scales yield a Mental Development Index (MDI) that has a mean of 100 and a standard deviation of 15.

Data Analytic Plan

Path models were evaluated with structural equation modeling using LISREL, with maximum likelihood estimation (Ver 8.54: (Jöreskog & Sörbom, 2003). Confirmatory factor analysis (CFA) was used to assess the measurement model. Univariate and bivariate distributions were initially examined for all variables, separately by group, and outlying values (> 2.5 SD from the mean or regression line) were removed. Missing data were imputed using the Expected Maximization (EM) algorithm in PRELIS.

Multiple indices of fit were examined (Wass, Bihun, Hager, & Haith, 1998, April). In addition to the overall goodness-of-fit chi-square (normal theory weighted least square) statistic, model fit was evaluated with the root mean square error of approximation (RMSEA; (Brown & Cudeck, 1993), an absolute fit index, which ranges from 0 to infinity, and the comparative fit index (CFI; (Bentler, 1990), which measures how well the sample covariance structure is reproduced by the hypothesized model. A RMSEA of $< .05$ indicates a good fit as does a CFI $> .90$.

Results

Preliminary Considerations

Attrition—Background characteristics, as well as 12-month scores on infant information processing measures, were similar for those with and without MDI data at 2 or 3 years as determined by *t*-tests.

Descriptive Statistics—Preterm/full-term differences for all measures are shown in Table 1. As reported previously, at 12 months preterms had poorer attention (Rose et al., 2001; Rose, Feldman, & Jankowski, 2002), poorer recognition memory (Rose et al., 2001), poorer recall memory (Rose, Feldman, & Jankowski, 2005), and slower encoding speed (Rose, Feldman, &

Jankowski, 2002). MDIs at 2 and 3 years were also significantly lower in preterms than full-terms. Because gender is often considered an important moderator of preterm status, 2 (full-term/preterm) by 2 (gender) ANOVAs were carried out for each measure. The only main effect of gender was for 2-year MDI which was higher for females ($M = 87.78$; $SD = 15.95$) than males ($M = 81.29$; $SD = 14.52$), $F(1,157) = 6.62$, $p < .05$; there were no significant interactions with birth status. Accordingly, gender was dropped from further consideration.

Bivariate relations—Initially, separate correlation (and covariance) matrices were computed for preterms and full-terms. Fewer than 5% of the correlations differed significantly between groups. Moreover, the LISREL procedure described by Green (Green, 1992) indicated that the covariance matrices for the two groups did not differ significantly, $\chi^2(45) = 55.73$, $p > .10$. Accordingly, the data were combined across groups. Correlation coefficients between all principal measures are shown in Table 2, partialled for birth status.

As can be seen, attention and speed were moderately correlated with one another. Both were related to visual recognition memory, with speed being additionally related to cross-modal transfer. Measures from three of the constructs – recognition, recall and representational competence – were related to later MDI. The two indicators of the constructs attention, recognition, recall, and MDI correlated positively, with r ranging from .21 to .78.

From Birth Status to Later MDI: Mediation by 12-Month Cognition

A structural model was specified to test the hypotheses that 12-month information processing would mediate the relation of birth status to 2- and 3-year MDI and that the infant measures would influence one another in a cascading fashion. That is, that the two elementary infant information processing abilities – attention and speed—would influence the three more complex infant abilities – recognition, recall and representational competence – which would, in turn, influence later MDI. This model included (a) paths from birth status to each of the five infant abilities and later MDI, (b) paths from the two more elementary abilities to the three more complex ones, and (c) paths from each of the five infant abilities to later MDI. The cascade posits that attention and speed would influence MDI indirectly, through their influence on the more complex abilities, while they would not have direct effects on MDI.¹

Birth status was coded 1 for children born at term and 0 for those born prematurely, error was allowed to correlate between the two indicators of attention and the single indicator of speed, and all measures were scaled in the same direction with higher scores reflecting better performance. This analysis included the 167 children having data at 12 months and 2- or 3-years; missing data points (3.8%) were imputed using EM estimation.

The results are depicted in Fig 1. The model provided a good fit to the data, $\chi^2(28) = 29.61$, $p = .38$, $RMSEA = .02$, $CFI = .99$, with the model accounting for 51% of the total variance in MDI. The standardized estimates, which allow for comparisons between paths, are shown in Fig 1, along with their significance level. (Disturbance terms and the correlated error between indicators of attention and speed are not shown.)

Three points are noteworthy. First, the relation of birth status to later MDI was entirely mediated by infant measures. The direct path was non-significant, standardized $\beta = -.03$ ($t = -.27$, ns), whereas the standardized indirect effect through 12-month information processing was significant, .22 ($t = 2.03$, $p < .05$). Thus, the lower scores of preterms on the Bayley MDI at 2

¹The model tested at 12 months is similar to one previously tested using 7-month data from this cohort. They differ principally in that the 12-month model: (1) included measures of recall memory, and (2) represented performance on the Bayley MDI at 2- and 3-years by a latent variable, rather than treating each as separate endpoints.

and 3 years can be attributed to their poorer information processing, as indicated by the 12-month measures.

Second, the three more complex infant measures – recognition, representational competence, and recall – were all *directly related* to MDI. The standardized direct effects for each of these constructs $\beta = .60$ ($t = 1.99, p < .05$), $\beta = .38$ ($t = 5.17, p < .01$), and $\beta = .36$ ($t = 3.36, p < .01$), respectively.

Third, in accord with the cascade model, the two more elementary infant abilities -- attention and speed—were only *indirectly related* to MDI, through the more complex abilities (visual recognition memory and representational competence). The standardized indirect effects of attention and speed on MDI were $.22$ ($t = 1.65, p = .10$) and $.34$ ($t = 2.12, p < .05$), respectively.

Because the direct paths from attention and speed to MDI were not significant, they were removed (set to zero) and the model was re-evaluated. This reduced model similarly fit the data, $\chi^2(30) = 33.32, p = .29, RMSEA = .03, CFI = .99$, and did not differ from the original one, $\chi^2_{\text{difference}}(2) = 3.89, ns$.

These results are consistent with a true cascade of effects, with attention and encoding speed influencing recognition memory and representational competence, which in turn influence later mental ability. The cascade model found here replicates that found with 7-month information processing (Rose et al., 2005)

From Birth Status to later MDI: Continuity and change from 7- to 12-months

A longitudinal extension of the above model was specified to examine the role played by continuities from 7- to 12-months in mediating relations between birth status and later MDI. The information processing measures included in this model were those that had been shown to have direct relations to later MDI, namely, 7- and 12-month visual recognition memory and representational competence, plus 12-month recall.

The new model included (a) direct pathways from birth status to all five information processing measures and MDI, (b) direct pathways from the two 7-month measures (recognition memory and representational competence) to their 12-month counterparts, and (c) direct paths from all five information processing measures to MDI. If the contribution from the 7-month measures to MDI is indirect, only through their 12-month counterparts, then the 7-month measures would be said to contribute because of their cross-age continuity.

Again, birth status was coded 1 for children born at term and 0 for those born prematurely, the error terms of attention and speed were allowed to correlate in theta epsilon, and all measures were scaled in the same direction, with higher scores reflecting better performance. As before, missing data (3.1% of the data points) were imputed using EM. The sample size is the same as in the first study because all infants with 12-month data also had 7-month data.

Results are shown in Fig 2. The model provided a good fit to the data, $\chi^2(32) = 37.96, p = .22, RMSEA = .03, CFI = .98$.

Several points are noteworthy. First, there were significant cross-age continuities for both visual recognition memory and representational competence. Second, there were significant direct paths from 7-month visual recognition memory to later MDI, $\beta = .48$ ($t = 2.20, p < .05$), from 12-month recall, $\beta = .27$ ($t = 2.81, p < .01$), and from both 7- and 12-month representational competence, $\beta = .16$ ($t = 2.34, p < .05$) and $\beta = .36$ ($t = 5.21, p < .001$), respectively. There was also a significant indirect path from 7-month representational competence to later MDI, $\beta = .10$ ($t = 2.98, p < .01$). The direct effects of 7-month visual recognition memory and

representational competence to later cognition indicate that the effects of these early measures were not entirely mediated by their 12-month counterparts. The effect of recall (assessed only at 12 months) was independent of the other two abilities. Consistent with results obtained when data from the two ages were analyzed separately, birth status had only an indirect effect on later MDI, and was mediated by the infant information processing variables, $\beta = .30$ ($t = 3.19$, $p < .01$).

Discussion

The present study confirms the role of infant abilities as the wellspring of individual differences in later cognition, expands our knowledge of the structure of infant cognition, and deepens our understanding of the developmental transformations of infant abilities over the second half of the first year of life. There were three major findings. First, infant information processing -- attention, speed, recognition, recall, and representational competence -- completely mediated the effect of prematurity on later cognition. Second, there was confirmation of a cognitive cascade in infancy, with a hierarchical ordering of abilities such that speed and attention (thought to be elementary abilities) influenced recognition memory and representational competence (thought to be more complex abilities). The cascade at 12-months was remarkably similar to that previously found at 7 months. Third, while continuities from 7 to 12 months partly explain the relation of 12-month information processing to later MDI, there were also independent contributions from information processing at 7 months, suggesting developmental transformations in the way infant abilities relate to later cognition.

Infant Information Processing: Foundation of Later Cognition

The findings from this study support the idea that infant information processing abilities are the foundation of later cognition. The participants were preterms and full-terms who had been followed from infancy to 2 and 3 years. Preterms showed deficits relative to full-terms at 12 months year on many of the information processing abilities assessed here, including attention, speed, recognition and recall. These deficits, like those found earlier, at 7 months, accounted for the lower developmental levels found among preterms later on, when they were 2 and 3 years of age (Rose, Feldman, Jankowski et al., 2005). The persistence of these deficits from 7 to 12 months, bolsters the contention that individual differences in later cognitive abilities have their roots in infancy.

A major difference at 12 months has to do with recall, which entails invoking stored representations in the absence of perceptual support and emerges only in the second half of the first year of life (Carver & Bauer, 2001; Nelson, 1995, , 1997). Recall was related later mental development independently of recognition memory and representational competence but was not involved in the cognitive cascade, in that it was influenced by neither attention nor encoding speed. The measure of speed used here assessed the time needed to encode the shape of static objects, and may not have adequately captured the time needed to encode the dynamic sequences of events involved in the recall tasks. Similarly, the type of attention assessed here may have been more relevant to static stimuli than to dynamic sequences; focused attention might be more germane to recall.

The Cognitive Cascade: A Fundamental Feature of Infant Cognition

Given the considerable developmental change in many aspects of cognitive function from 7- to 12-months, the stability of structure found here was by no means a foregone conclusion; it helps dispel the long-held view that infant cognition is too chaotic to study seriously.

Evidence for a cascade of effects, such that more elementary infant abilities influence more complex ones which, in turn, influence later cognition, was present at 12 months much as it

was at 7 months. At both ages, models which allowed only indirect paths from attention and speed to later MDI (having their direct paths set to zero) fit the data as well as models having both direct and indirect paths free. Thus, despite very rapid brain and behavioral development, this cascading structure of cognition remains fairly stable across age.²

It should be noted that the cascade model, as applied to older children and adults, originally posited that age-related changes in processing speed drive age-related changes in working memory, which, in turn, affect general ability, particularly fluid intelligence (Hale, 1990; Kail & Salthouse, 1994). Here the model has been modified to characterize the sequence of effects within an age. The fit of the model at both 7- and 12-months supports its applicability in the current context.

Continuity and Change—According to a strict homotypic continuity model, we would have anticipated that the route from infant abilities to later cognition would be a straightforward one, where early abilities influenced their later counterparts, which in turn influenced cognition. Thus, given that the separate analyses at 7 and 12 months had each shown direct links of recognition memory and representational competence to later MDI, we would have anticipated that recognition memory from 7 months would have had only an indirect influence on MDI, via a path going through its 12-month counterpart. The same would have been true of representational competence.

However, as it turned out, the influence of 7-month representational competence on later MDI was both direct and indirect; thus only part of the 7-month construct was mediated by its 12-month counterpart. Moreover, the influence of visual recognition memory on MDI was solely from 7 months. Taken together, these findings suggest that, as infants mature, age-related changes in their information processing abilities affect how these abilities relate to later cognition.

With respect to representational competence, there are at least two reasons why there was only partial mediation of the 7-month construct through the 12-month one. First, there appear to be major developmental changes in the strategies underlying cross-modal transfer during this period, with younger infants focusing more on featural information (a sharp corner, or rounded edge) and older infants on configural information (Bushnell, 1994). Second, there are major changes in underlying brain structure during this period, particularly later-maturing regions of the hippocampus (Nelson, 1995). Nelson (Nelson, 1997) has proposed that the basis for cross-modal transfer changes between 6 and 12 months, as a more mature form of explicit memory develops, one which depends more on developing cortical structures (e.g., area TE) and the further elaboration of limbic structures (e.g. dentate). Also, at around 12 months, the trisynaptic loop of the hippocampus becomes complete (Mori, Abegg, Gahwiler, & Gerber, 2004). This loop receives input from cortical areas involved in multi-modal processing (temporal, parietal, prefrontal, and cingulate), processes it, and sends it back to the cortical areas from which it originated (see (Colombo & Cheatham, 2006). In light of these factors, it is perhaps not surprising that different facets of this complex ability are captured at the two ages and that these contribute independently to later cognition.

For visual recognition memory, on the other hand, the 7-month assessment apparently captured variance relevant to MDI above and beyond that contributed by its 12-month counterpart. This finding is compatible with a review of several earlier reports which concluded that assessments

²The only difference between the 7 and 12-month models was that the path coefficient from attention to visual recognition memory was not significant at 7 months. However, the analyses in the earlier report had been based on pair-wise correlation matrices done separately for 2- and 3-year outcomes. When the analysis was repeated, with the same methods used here, namely, with EM imputation of missing data points, and a latent MDI variable, this path was significant. The model provided a good fit to the data, $\chi^2(15) = 16.72$, $p = .34$, RMSEA = .03, CFI = .98 and accounted for 40% of the total variance.

of visual recognition from the middle of the first year of life are more strongly predictive of later IQ than are those from the end of the first year (McCall & Carriger, 1993). Given that visual recognition memory is one of the earliest emerging forms of memory, the 7-month assessment may occur during a period of developmental transition that magnifies individual differences that are particularly meaningful for later cognition. To the extent this is true, the relation of 12-month visual recognition memory to MDI in the model containing only 12-month variables was due to the continuity in visual recognition memory from 7-to 12-months.

The present findings, along with the previously presented cascade models of Rose et al. (Rose, Feldman, Jankowski et al., 2005) and Bornstein et al. (Bornstein et al., 2006) suggest attractive alternatives to the classic homotypic model of cross-age continuity wherein each cognitive ability – elementary or broad – predicts itself at later ages. In Bornstein's model, an elementary ability in infancy (habituation) influenced increasingly more general abilities across successive ages. By positing a developmental cascade, these alternative models increase our sophistication in thinking about continuity from infancy. They are consonant with a developmental systems approach that sees abilities as influencing one another rather than as all being determined by a single underlying causal ('g') factor (van der Maas et al., 2006).

In summary, the present findings show that (a) infant information processing mediates the impact of preterm birth on later cognition, (b) infant cognition is characterized by a cognitive cascade, (c) this cascade is relatively stable over age, and (d) although some aspects of infant cognition show substantial stability across age, assessments from different ages have aspects that make separate predictive contributions. These findings imply that intervention at lower levels of cognition in infancy may affect later outcomes.

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Figure 1.

The pathways from prematurity and infant information processing at 12 months to MDI at 2- and/or 3-years. Standardized coefficients for all paths are shown. * $p < .05$, ** $p < .01$.

Figure 2.

The pathways from prematurity and infant information processing at 7 and 12 months to MDI at 2- and/or 3-years. Standardized coefficients for all paths are shown. $^{\dagger} p < .10$, $* p < .05$, $** p < .01$.

Table 1

Descriptive Statistics

	Full-terms			Preterms			<i>t</i>
	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	
<i>Infant Measures (12 months)</i>							
Recognition Memory							
Novelty score (Rose VPC Task)	126	58.68	5.24	56	57.06	5.75	1.87 ⁺
Novelty score (Fagan VPC Task)	128	60.29	5.12	54	58.30	6.79	2.16 [*]
Processing Speed							
Trials to criterion (Continuous Familiarization)	117	10.00	6.21	55	12.89	9.71	2.36 [*]
Representational Competence							
Novelty score (Cross-modal Task)	118	48.32	4.27	52	48.40	4.86	.11
Attention							
Mean look duration composite ^a	126	-.14	.59	56	.31	.72	4.45 ^{**}
Shift rate composite ^a	126	.14	.71	56	-.30	.67	3.96 ^{**}
Recall Memory							
Percentage correct (Elicited Imitation)	121	42.17	19.64	55	33.69	17.50	2.75 ^{**}
Level (Symbolic Play)	113	7.45	2.49	53	6.32	2.73	2.64 ^{**}
<i>Outcome Measures</i>							
MDI – 2 Years	108	86.02	14.01	54	80.70	17.60	2.09 [*]
MDI – 3 Years	104	89.67	13.40	49	85.22	11.57	1.99 [*]

Note 1 – VPC = Visual Paired-Comparison Task.

^a An average of variables standardized to a mean of 0.

* $p \leq .05$.

*** $p \leq .01$

Table 2
Correlations: 12 Month Measures and Bayley Scores at 2 and 3 years

	1	2	3	4	5	6	7	8	9	10
1. Novelty score (Rose VPC)	--	.24**	-.21**	-.05	-.21**	.23**	.01	.15	.22**	.19*
2. Novelty score (Fagan VPC)		--	-.21**	.12	-.05	.07	.04	.09	.19*	.14†
3. Trials to criterion (Continuous Familiarization)			--	-.17*	.33**	-.36**	-.03	.03	-.11	-.04
4. Novelty score (Cross-modal)				--	-.13	.08	.09	.06	.35**	.31**
5. Mean look duration composite					--	-.78**	.01	.01	.00	-.03
6. Shift rate composite						--	.00	-.06	.08	.12
7. Elicited imitation							--	.49**	.29**	.31**
8. Symbolic play								--	.22**	.21*
9. 2-year MDI									--	.76**
10 3-year MDI										--

Note 1 – Correlations are partialled for birth status and are restricted to children having data at 12 months and 2- and/or 3-years.

Note 2 – VPC = Visual Paired-Comparison Task. MDI = Bayley Mental Developmental Index.

* $p \leq .05$.

** $p \leq .01$.