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Information Processing in Toddlers: Continuity from Infancy and Persistence of Preterm Deficits

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Abstract

The present report assesses information processing in the toddler years (24 and 36 months), using a cohort of preterms (<1750 g) and full-terms initially seen in infancy. The children received a battery of tasks tapping 11 specific abilities from four domains – memory, processing speed, attention, and representational competence. The same battery had been used earlier – at 7 and 12 months. There were four main findings. (1) Preterms showed no ‘catch-up,’ but rather persistent deficits in immediate recognition, recall, encoding speed, and attention. (2) There was significant continuity from infancy through the toddler years for most aspects of information processing. (3) These specific abilities combined additively to account for global cognitive ability, consistent with the componential theory of intelligence. (4) Toddler information processing abilities completely mediated the relative deficits of preterms in general cognitive ability. Thus, although the toddler years have often been characterized as a period of discontinuity and transformation, these results indicate that continuity prevails for information processing abilities over the first three years of life.

Information processing studies have largely neglected the period of toddlerhood (2-3 years). By contrast, studies of information processing in the first year of life have blossomed over the past few decades. As detailed below, there is now considerable knowledge about the cognitive capabilities of infants and about how basic information processing abilities from this period form the building blocks of later cognition. Considering that later IQ can be predicted from information processing in the first year of life, one would expect these infant cognitive abilities would show continuity through the toddler years. Yet at present there is little evidence that this is so. Moreover, a long tradition of thought views the toddler period as one of major transitions and cognitive discontinuities. This tradition stems largely from the thinking of Piaget and the failure of standardized infant tests to predict later IQ. The present study fills this gap in our knowledge about information processing abilities in toddlerhood, and traces the sources of these abilities to continuity with information processing in infancy.

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Early studies of infant cognition, between the 1930's and the 1960's, concentrated heavily on developing standardized tests for assessing age-related changes in developmental functioning (Bayley, 1933, 1969; Cattell, 1940; Gesell & Amatruda, 1954). As it turned out, however, the predictive validity of these tests was poor (Fagan & Singer, 1983; Kopp & McCall, 1982). Often these developmental tests even failed to differentiate normally developing infants from those at risk for later cognitive compromise (Drillien, Thompson, & Burgoyne, 1980). These findings, which were replicated repeatedly, were reinforced by the work of Piaget (Piaget, 1962), who argued that abrupt and profound qualitative changes characterized this period. Together, they led to the prevalence of the ‘discontinuity’ view, in which early mental abilities were held to differ in fundamental ways from later mental abilities. Early intellectual development was thought to undergo a series of transformational shifts due to the advent of language and the emergence of other symbolic capacities. As age increased, cognitive functions were expected to stabilize.

However, items on standardized infant tests differ in fundamental ways from those on childhood tests. When concerned with the first year of life, such tests draw largely on the sensori-motor repertoire, with many items relying on motor development, fine motor control, imitation, and affective responsivity. Thus, the inability of traditional infant tests to predict later intelligence might be viewed as a failure of convergent validity, rather than instability in early intelligence (Colombo, 1993; Rose & Feldman, 1990; Rose & Tamis-Lemonda, 1999) That is, the basic problem may lie in the differing content of infant and childhood tests. Infant tests simply did not tap the same cognitive skills required for successful performance on tests of standardized intelligence, such as attention, processing speed, discrimination, memory, and symbolic representation.

The discontinuity view of mental development was challenged in the past two decades by work which took the information processing approach as its point of departure. This work, which has centered on the first year of life, with endpoints well into childhood or adolescence, has resulted in three major findings. First, measures of specific aspects of information processing from the 1st year, such as attention, memory, processing speed, and representational competence, have been found to relate to more general cognitive ability, correlating significantly with measures of intelligence at later ages, from 2 through 21 years (Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004; DiLalla et al., 1990; Fagan, 1984; Fagan, Holland, & Wheeler, 2007; Fagan & McGrath, 1981; Rose, Slater, & Perry, 1986; Rose & Feldman, 1995, [1997]; Rose, Feldman, & Jankowski, 2005a; Rose, Feldman, Jankowski, & Van Rossem, 2005, [2008]; Rose, Feldman, & Wallace, 1992; Rose, Feldman, Wallace, & Cohen, 1991; Sigman, Cohen, Beckwith, Asarnow, & Parmelee, 1991; Tamis-LeMonda & Bornstein, 1989); for meta-analytic reviews see (Bornstein & Sigman, 1986; McCall & Carriger, 1993). Second, these infant abilities have been found to support the componential approach, in that they combine additively in accounting for later intelligence (Rose, Feldman, Jankowski et al., 2005; Rose et al., 2008; Rose, Feldman, Wallace, & McCarton, 1991). Third, many of these early abilities have proved to be sensitive to markers of risk for later cognitive deficits, such as, preterm birth, prenatal exposure to alcohol, malnutrition, and early exposure to teratogens (de Haan, Bauer, Georgieff, & Nelson, 2000; Jacobson, Fein, Jacobson, Schwartz, & Dowler, 1985; Jacobson, Jacobson, Sokol, Martier, & Ager, 1993; Oken et al., 2005; Rose, 1994; Rose, Feldman, & Jankowski, 2001a, 2002; Rose, Feldman et al., 2005a; Rose, Feldman, Wallace, & Cohen, 1991; Singer, Drotar, Fagan, Devost, & Lake, 1983).

As noted above, the transition from the first year of life to the toddler period is not well understood (Blaga et al., 2009). Indeed, less is known about the second year of life than about any other phase of the life span (Reznick, Corley, & Robinson, 1997) and, with the exception of recent work on recall memory (Bauer, 2002, 2006; Bauer, Wiebe, Carver, Waters, & Nelson, 2003; Hayne, 2004), data on basic information processing in toddlers is largely absent.

Further, it is unclear whether many of the early negative effects of risk, such as the deficits found in preterm infants (Rose et al., 2001a; Rose, Feldman, & Jankowski, 2002; Rose, Feldman et al., 2005a; Rose, Feldman, Wallace, & McCarton, 1991; Rose, Feldman, Wallace, & McCarton, 1989), persist into toddlerhood. The evidence with respect to this issue from older cohorts is mixed. Some studies have found that preterms ‘catch up’ to full-terms with age, due presumably to neural plasticity and functional recovery (Ment et al., 2003), while others have found deficits to persist and even increase over age (Allen, 2002; Aylward, 2002; Rose & Feldman, 1996; Saigal, Hoult, & Streiner, 2000).

The present study is the outgrowth of a project begun to examine the sources of preterms' cognitive deficits in infancy drawing on two research traditions: the componential approach to intelligence (Detterman, 1987) and the information-processing approach to cognitive development. This latter tradition brought with it a rich repertoire of laboratory-based tasks with which to explore the cognitive abilities of infants (Fodor, 1983; Karmiloff-Smith, 1992; Sternberg, 1985). The assumptions behind the original work were (1) that individual, and group, differences in many elementary components of more complex cognitive skills could be assessed, in principle, in the first year of life, and (2) that individual differences in these elementary abilities would prove enduring, sensitive to risk, and predictive of later intelligence.

Here we extend the study of information processing to the toddler years (24 and 36 months), using the same battery of non-verbal tasks previously used in the first year of life. The battery consists of 11 tasks covering four cognitive domains -- memory, attention, processing speed, and representational competence (with tasks age-adjusted for timing parameters). The sample is a longitudinal cohort of preterms (<1750g) and full-terms who have now been seen from infancy through three years of age. In this report, we address four questions about information processing in toddlers.

1. *Do the negative effects of prematurity persist*? We have previously shown that measures from this battery are sensitive to prematurity (birthweight < 1750 g) at 5, 7, and 12 months, with preterms showing deficits relative to their full-term controls (Rose et al., 2001a; Rose, Feldman, & Jankowski, 2002, 2003a, 2003b; Rose, Feldman et al., 2005a; Rose, Feldman, Jankowski, & Caro, 2002). Here, we examine the persistence of these preterm deficits to the toddler period.
2. *To what extent do these specific cognitive abilities account for general cognitive ability*? Previously, we found that the measures from our battery form differentiated dimensions of cognition in infancy (Rose, Feldman, & Jankowski, 2004, 2005b), and that latent variables reflecting these dimensions predict later general cognitive ability (MDI) at 24 and 36 months, (Rose, Feldman, Jankowski et al., 2005; Rose et al., 2008). Here, we examine the extent to which measures from this battery collectively account for contemporaneous measures of general cognitive ability at 24 and 36 months.
3. *To what extent are there continuities in these core aspects of cognitive ability from infancy to the toddler years*? Previously, we showed specific continuity for a number of measures from this battery across the first year of life -- 5, 7, and 12 months (Rose et al., 2001a; Rose, Feldman, & Jankowski, 2001b; Rose, Feldman, Jankowski et al., 2002). Here, we examine continuities for all the measures in the battery across the period of toddlerhood (24 to 36 months) and between the infant and toddler periods.
4. *To what extent do deficits in information processing account for preterm/full-term differences in general cognitive ability*? In earlier work, we found that information processing deficits at 7 and 12 months entirely accounted for the difference between preterms and full-terms in toddler MDI. Here we examine whether information processing deficits in the toddler years perform a similar mediational function.

Method

Participants

Participants were full-term and preterm infants who were enrolled in a prospective, longitudinal study of cognitive development. Children were seen three times in the first year of life (5, 7, and 12 months), and then again at 24 and 36 months for follow-up. The present report concerns performance on a battery of tasks tapping attention, speed, memory, and representational competence given at 24 and 36 months.

The original sample 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).

At 24 months, follow-up rates were 82.6% for full-terms and 91.5% for preterms (N = 119 full-terms and N = 54 preterms); at 36 months, these figures were 76.4% and 84.7% (N = 110 full-terms and N = 50 preterms). Subject loss was principally due to mothers returning to work after maternity leave and the attendant scheduling difficulties.

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.

Sample Characteristics—The background characteristics of the preterms and full-terms who returned for the 24- and/or 36-month follow-up were (as at intake) similar in gender, birth order, ethnicity, parental education, and socio-economic status (SES), with 52.8% male, 36.7% first born, and 84.4 % either Black or Hispanic. Maternal education averaged 13.3 years (*SD* = 2.2) and SES, as assessed by the Hollingshead Four-Factor Index of Social Status (Hollingshead, 1975) averaged 35.1 (*SD* = 12.9). English was the only, or the primary, language spoken in the home for 87.2% of the sample. For further details on medical and background characteristics see (Rose et al., 2001a).

Procedure

The information processing measures considered here assessed different types of memory (immediate and delayed recognition, recall, working memory), representational competence (cross-modal transfer, anticipations), processing speed (psychomotor reaction time, encoding speed) and attention (look duration, shift rates). Developmental level was assessed with the Bayley scale.

The tasks, which with one exception had all been used in earlier waves of testing at 7 and 12 months, were modified to be age-appropriate, so that there would be no floor or ceiling effects and inter-individual variability would be maximized.[1] The modifications included shortening presentation and test times, increasing the stringency of learning criteria, and in some instances, increasing stimulus complexity. Changes were based on extensive piloting. In what follows, the measures derived from each task are printed in *italics*.

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[1] Recall was not included in the 7-month battery.

Information Processing

Memory

Immediate Recognition: Immediate recognition was assessed with two visual paired-comparison tasks (VPC). In both, children 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 9 problems, 5 using black-and-white photographs of faces as stimuli and 4 using colorful abstract patterns. Familiarization times for Faces and Patterns were 7 and 3 s at 24-months, and 5 and 3 s at 36 months; test times for all stimuli were 6 s at 24-months and 4 s at 36 months (Rose et al., 2001a). The other task, developed by Fagan (Fagan & Sheperd, 1989), comprised of 10 face problems, had a similar format. Composites for each test were created by averaging individual novelty scores.

Delayed Recognition: To assess delayed recognition, children were initially habituated to three objects in succession, using a modified infant-controlled procedure (Diamond, 1990), and then, after a delay, given a series of test trials in which each habituated object was successively paired with a new object (for 6 s at 24-months and 4 s at 36 months). This habituation-test procedure was repeated three times, with delays of 1, 3, and 5 min, respectively, making nine problems in all. Presentation times during the habituation phase were the same at both ages: the child was allowed to look at the object until he/she had 2 1-s looks away, or had accumulated 10 s of looking, whichever came first. The overall *Novelty Score*, computed by averaging novelty scores for each of the 9 problems, was used here (Rose et al., 2004).

Recall Memory: Recall memory was assessed with the elicited imitation task (Bauer, 2002). Here, the examiner modeled four event sequences (e.g., 'make a rattle:' place a small block on a paddle, cover it, and then shake the paddle to create a rattle sound). At 24 months, sequences contained 3-5 actions and at 36 months, 5-12 actions; sequences were always modeled in the same order. Then, after a 15-min delay, the child was given the props for each sequence, in turn, and his/her accuracy at reproduction scored (Rose, Feldman et al., 2005a). Recall memory, measured by the *Percentage of Target Actions Reproduced* for each event sequence, was averaged over sequences.

Short-term Memory Capacity: This aspect of memory was assessed with a span task in which spans of 1, 2, 3, and 4 items (colorful objects) were presented at 24 months, and spans of 2, 4, and 6 items were presented at 36 months. Spans were presented in ascending order. For a span of 1, the procedure was similar to that described above for the VPC procedure. For the remaining spans, the infant was familiarized to two or more objects in succession and then immediately given a series of test trials in which each successive familiar object was paired with a new one. On familiarization trials, an object was displayed until the infant accumulated 2 s of looking at 24 months, 1.5 s at 36 months. On test, paired stimuli were presented for 6 s at 24 months and 4 s at 36 months. *Span Length* was measured by the highest number of items 'recognized' (defined by a novelty score ≥ 55%) from any of the four spans (Rose et al., 2001b).

Speed

Psychomotor Speed (RT): This aspect of processing speed was assessed with reaction time (RT) measures from the VExP task (Haith, Hazan, & Goodman, 1988). In this task, eye movements are recorded as infants watch a series of pictures that appear to the left and right of center on a video monitor. There were 10 baseline trials, where the left-right placement of images was random, and 60 series trials, where the images were presented in a predictable right-right-left (RRL) sequence. At both ages, stimulus durations were 500 ms; inter-stimulus intervals were 720 ms. Using a 150 ms cut-point to separate anticipatory from reactive saccades, responses that occurred ≥ 150 ms after stimulus onset were scored as RT (Haith et al., 1988) Performance was indicated by *Mean RT* on baseline trials and *Mean RT* on post-baseline, or series trials (Rose, Feldman, Jankowski et al., 2002).

Encoding Speed: This aspect of speed was assessed with the ‘continuous familiarization’ task, in which infants were presented with a series of paired photographs, one of which changed across trials. Trials lasted for 3 s at 24 months and 1.5 s at 36 months; testing continued until infants showed a consistent preference for the new one – defined, at 24 months, as 4 out of 5 consecutive trials having a novelty score > 55% (but < 100%) and, at 36 months, as 6 out of 7 such trials. A maximum of 36 trials were given at both ages. Encoding speed was measured by *Trials to Criterion*, the trial on which the criterion was met, or 36 trials if it was not met (Rose, Feldman, & Jankowski, 2002).

Representational Competence—Representational competence, which concerns the ability to extract the commonalties from experiences and to represent them in some abstract way, was assessed with two tasks.

Cross-modal transfer: The ability to extract information about shape from one modality and apply it to another was assessed with a task of tactual-to-visual transfer (Rose & Feldman, 1995; Rose, Feldman, Futterweit, & Jankowski, 1997; Rose, Feldman, & Wallace, 1988; Rose, Gottfried, & Bridger, 1978). This task, comprised of 11 problems, used 3-dimensional geometric forms as stimuli. At both ages, stimuli were presented for familiarization in the tactile mode for 15 s, and then, on test, the previously felt object and a new one were presented visually for 10 s. 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(Rose, Feldman, Wallace, & McCarton, 1991).

Anticipations: The ability to anticipate forthcoming events was measured by the VExP task described above. Saccades to the up-coming stimulus were considered to be anticipatory if they were initiated before the stimulus could be perceived, i.e., before stimulus onset, or within 150 ms of onset, the minimal time thought to be required to initiate a saccade (Haith et al., 1988). To successfully anticipate stimulus onset the child had to abstract the R-R-L rule governing changes in location for the fast-paced sequence of pictures (Canfield, Smith, Brezsnyak, & Snow, 1997; Rose, Feldman, Jankowski et al., 2002). The measure here was the *Percentage* of all series trials RTs that were ≤ 150 ms.

Attention

Look duration: There were six measures of *mean look duration (s)*, gleaned from four tasks: two from the ‘Rose’ test of immediate recognition (familiarization and test phase), two from the ‘Fagan’ test of immediate recognition (familiarization and test), one from the cross-modal task (test phase), and one from the continuous familiarization task (all trials). In each case, mean look durations were averaged over all problems in each task and phase (or all trials, in the continuous familiarization task). A composite was formed by standardizing all scores and then averaging them (Rose et al., 2004; Rose, Feldman et al., 2005b).

Shift Rate: 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 phase), one from cross-modal task (test phase), and one from continuous familiarization (all trials). Mean shift rates were derived from each task and phase; a composite was formed by standardizing the scores and then averaging across tasks (Rose et al., 2004; Rose, Feldman et al., 2005b).

Developmental level: Developmental level was assessed at 24 and 36 months with *Bayley Scales of Infant Development* (Bayley, 1993), which yields a Mental Development Index (*MDI*) that has a mean of 100 and a standard deviation of 15.

Results

Information Processing in Toddlers

Preliminary Considerations: Attrition—Background characteristics (and scores on earlier assessments of infant information processing) were similar for those who did and did not return at 24 or 36 months, as determined by t-tests.

Descriptive Statistics: 24 months—Means and standard deviations for all 24-month measures, along with t-tests assessing the significance of preterm/full-term differences, are shown in Table1.

Memory: At 24 months, both groups were able to recognize the stimuli, both immediately and after a delay, as indicated by novelty scores significantly above the chance value of 50% (on the Rose, Fagan and Delayed Recognition tasks). They were also able to hold between 2 and 3 items in short-term memory (on the span task) and recall more than 50% of the actions from the event sequences. Nonetheless, on four of the five tasks the performance of preterms was significantly poorer than that of full-terms.

Processing speed: Preterms were significantly slower than full-terms in encoding stimuli in the continuous familiarization task. The speed of orienting to stimuli on the VExP task did not differ between groups.

Representational competence: Novelty scores on the cross-modal transfer task hovered around chance (50%) and anticipations occurred on about 20% of the series trial on VExP; preterms and full-terms did not differ significantly from one another on either measure.

Attention: Preterms showed less mature patterns of attention on both measures, as indicated by significantly longer mean look durations and significantly lower shift rates (less frequent shifts of gaze between paired stimuli) than full-terms.

General Cognitive Ability: Preterms had significantly lower scores on the Bayley MDI than the full-terms; the difference was about 1/3 of a standard deviation.

Descriptive Statistics: 36 months—Means and standard deviations for all 36-month measures, along with t-tests assessing the significance of preterm/full-term differences, are shown in Table 2.

Memory: Despite the fact that familiarization times at 36-months were reduced from those used at 24-months, the children continued to show immediate and delayed recognition (novelty scores were significantly greater than 50% on the Rose, Fagan and Delayed Recognition tasks). They also held more than 4 items in short term memory, and recalled between 70% and 75% of the actions from the event sequences. The relative deficits of preterms on immediate recognition and recall persisted at this age.

Processing speed: Again, preterms continued to be significantly slower at encoding stimuli than full-terms, whereas the groups did not differ in their reaction times on the VExP task.

Representational competence: As at 24-months, there were no preterm/full-term differences in either cross-modal performance or in the number of anticipations shown in the VExP task.

Attention: Preterms continued to show significantly less mature patterns of attention, with longer mean look durations and lower shift rates than preterms.

General Cognitive Ability: Preterms also continued to have significantly lower Bayley MDI scores than the full-terms.

Summary—At both ages, the results were remarkably similar, with preterms showing poorer immediate recognition memory and recall, slower encoding, and less mature attention. These similarities occurred despite the more stringent task demands introduced at the older age (e.g., reduced familiarization and test times, shorter stimulus presentations, more stringent criteria, etc.).

Within-Age Correlations: 24 and 36 Months—Initially, separate correlation matrices were computed for preterms and full-terms. Since fewer than 5% of the correlations differed significantly between groups, the data for preterms and full-terms were combined. Within and cross-age correlation coefficients (partialed for birth status) are shown in Table 3, where correlations at 24 months are above the diagonal and those at 36 months are below.

Correlations were, by in large, similar at the two ages. Within domain, measures of immediate and delayed recognition correlated significantly with one another as did the two indicators of attention (look duration and shift rate), and the RT measures from VExP. Across domain, processing speed correlated with measures of attention and memory (especially recognition). In addition, a number of the information processing measures – including immediate recognition, recall, encoding speed, and cross-modal transfer correlated significantly with general cognitive ability (MDI) at both ages.

Stability from 24- to 36-Months—The cross-age correlations from 24- to 36-months are given in the last line of Table 3. These figures indicate substantial stability over this one-year period despite numerous changes in task parameters and stimuli ($r = .19$ to $.53$; median $r = .39$). Clearly, then, individual differences in many of these core aspects of information processing show marked stability over the toddler period.

Toddler Information Processing and MDI: The Componential Approach—To assess whether the information processing measures combined additively to account for MDI, as would be expected according to the componential approach, multiple regressions were performed predicting 24- and 36-month MDI from concurrent information processing measures, with birth status included as a control. For these analyses, the two measures of immediate recognition memory were averaged to form a single composite. These regressions included only those information processing measures having a significant relation to MDI at either 24 or 36 months. Missing data on predictor variables (.8% at 24 months and 2.3 % at 36 months) were replaced with the sample mean.

Results are shown in Tables 4. In this table, the squared semi-partial correlation coefficient, sr^2, indicates the percentage of outcome variance uniquely attributable to each predictor, and the standardized partial regression coefficients, β, indicates the change in outcome (in standard deviation units) associated with one standard deviation increment in the predictor, all else being held constant.

There are three points of interest in Table 4. First, it is notable that four of the six information processing variables – encoding speed, immediate recognition, recall, and cross-modal transfer – have significant independent relations to 24-month MDI. Second, the effect of birth status was no longer significant when 24-month information processing was controlled. Third, these variables together accounted for nearly a third (32%) of the variance in 24-month MDI; and of this variance, most (72%) was due to the unique contributions of individual variables (Σ sr^2s/R^2).

A similar picture emerged between information processing and MDI at 36 months. Again, measures of immediate recognition, recall, and cross-modal transfer showed significant independent relations to MDI, the effect of birth status was completely mediated by information processing, and contemporaneous information processing accounted for nearly a third (31%) of the variance in 36-month MDI (with 68% of this amount uniquely accounted for by individual variables).

Continuities in Information Processing from Infancy to Toddlerhood

As noted earlier, the children in this sample had previously been assessed on all of these measures of information processing in earlier waves of testing in infancy at 7 and 12 months. By relating infant to toddler performance, we can assess the extent to which continuities from infancy account for performance in these toddlers.

To better characterize information processing from these two periods, measures were combined across age by averaging scores from *Infancy* (7 and 12 months) and *Toddlerhood* (24 and 36 months). Children had to have infant data (at 7 and/or 12 months; $N = 203$) *and* toddler data (at 24 and/or 36 months; $N = 180$) to be included in these analyses ($N = 170$ had data from both periods). Again, immediate recognition was represented by a composite from the Rose and Fagan tasks and, in the regressions, missing data on predictor variables (1.1% for both infants and toddlers) were replaced with the sample mean.

Cross-age Correlations: from Infancy to Toddlerhood—As before, separate correlation matrices were initially computed for preterms and full-terms. Again, because fewer than 5% of the correlations differed across groups, the data are collapsed across groups, with correlations partialed for birth status.

As can be seen in Table 5, with the exception of short-term capacity, all cross-age correlations from infancy to toddlerhood were significant, ranging from .18 to .37 (Md = .26). Additionally, several information processing measures (the same ones from both age periods) were related to toddler MDI, namely, immediate and delayed recognition, encoding speed, and cross-modal transfer. These relations with MDI ranged from .20 to .44.

Information Processing and MDI: The Componential Approach in Infants and Toddlers—Given the continuity between infant and toddler measures shown in earlier in Table 4, the issue arises whether the infant measures combine similarly to those from the toddler years in accounting for global cognitive ability. To address this issue we performed two simultaneous multiple regressions predicting toddler MDI, one using as predictors the infant measures of information processing and the other using the same measures from the toddler years. As can be seen in Table 6, in both cases, three aspects of information processing -- immediate recognition, recall, and cross-modal transfer—independently predicted MDI. Moreover, the amount of variance accounted for from infant information processing (29%) was fairly close to that accounted for by the contemporaneous toddler measures (42%). Again, using these measures again, most of the total variance accounted for was due to unique contributions from information processing measures (66% from the infant measures and 69% from the toddler).

Discussion

The present study, which was concerned with information processing in toddlers, focused on preterm deficits and continuity from infancy. The toddler years, 24 and 36 months, is a relatively understudied period in psychological research, and one often thought to be characterized by cognitive upheaval, re-organization, and transformation. The nature of early cognition was examined using a battery of 11 information-processing tasks covering four cognitive domains – memory, processing speed, attention, and representational competence. The children were participants in a longitudinal study of cognitive development, which had included age-appropriate versions of these same the tasks at 7- and 12-months. Thus, continuity in information processing could be examined across the first three years.

There were four main findings. First, there was no ‘catch-up’ in the preterms. At both ages, preterms showed a number of cognitive deficits, both in global functioning, as indexed by lower Bayey MDI scores, and in the information processing tasks designed to assess more elementary cognitive abilities. Their specific deficits included poorer immediate recognition, poorer recall, slower encoding speed, and more immature patterns of attention (longer look durations and fewer shifts of gaze). In the first year of life, these children had shown deficits in precisely the same areas (Rose et al., 2001a; Rose, Feldman, & Jankowski, 2002; Rose et al., 2003b; Rose, Feldman et al., 2005a). Thus, as toddlers, they continued to perform below their full-term counterparts, and continued to have difficulty in precisely those aspects of information processing with which they had difficulty in the first year of life.

Second, all aspects of information processing showed continuity over the first three years. There was no indication of the discontinuities that had been posited by much of the earlier literature. Cross-age correlations of information processing measures *within* the toddler years (i.e., from 24-36 months) were significant, and predominately in the 30s and 40s. Cross-age correlations *between* the infant and toddler years also tended to be significant, mainly in the 20s and 30s, consistent with the notion that the toddler abilities have their origin in infancy. These findings complement those that found continuity beginning at 12 months for psychometric tests (Blaga et al., 2009; Humphreys & Davey, 1988). The present results extend these findings by showing that (a) similar continuities exist for a wide variety of elementary information processing abilities, and (b) continuities for these elementary abilities have roots even earlier in the first year of life. These infant abilities may relate to later IQ, at least in part, because of their continuity over age.

Third, these elementary abilities combine additively to account for a considerable portion of the variance in intelligence, consistent with the componential view. In separate simultaneous regressions done at 24 and 36 months, most (over $2/3^{rds}$) of the total variance accounted for in contemporaneous MDI was due to unique contributions from the various information processing measures. Parallel results were obtained when accounting for toddler MDI with these same measures from infancy. It is striking that the abilities contributing independently to variance in MDI are largely the same in infancy as in the toddler years. Moreover, three of the individual measures – immediate recognition memory, recall, and cross-modal transfer--contributed independently of all others at every age, suggesting that they are core elements for the foundation of later cognition. The fact that infant measures predicted toddler MDI almost as well as contemporaneous measures buttress the notion that these foundational elements have their roots in infancy.

Fourth, it is noteworthy that toddler information processing abilities fully account for preterm/full-term differences in contemporaneous general cognitive ability. These findings for toddler information processing extend earlier work showing that similar deficits in infancy completely account for preterm children's more general deficits (Rose, Feldman, Jankowski et al., 2005;

Rose et al., 2008). The persistence into toddlerhood of deficits in these pivotal aspects of information processing suggests that the ultimate cognitive outcomes in preterms might be markedly improved by interventions targeting these particular abilities.

In summary, findings from the toddler years show that preterms continue to underperform on measures of specific abilities from the domains of attention, processing speed, memory, and representational competence (no ‘catch-up’). Specific abilities from these domains account for a substantial amount of variance in 24- and 36-month MDI, as well as for all of the preterm full-term difference in MDI. These findings mirror those obtained earlier in infancy, highlighting the enduring importance of information processing capabilities in the general cognitive competence of young children.

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Table 1

Preterm/Full-Term Differences: 24-months

	Full-terms			Preterms			
	N	**M**	**SD**	**N**	**M**	**SD**	**t-test**
Memory							
Immediate Recognition (composite)							
Rose VPC (% Novelty)	113	57.05	5.38	53	55.33	4.36	2.03*
Fagan VPC (% Novelty)	116	59.55	4.82	52	57.22	3.65	3.19**
Delayed Recognition (% Novelty)	110	57.97	7.09	50	56.80	7.01	.97
Recall – elicited imitation (% Correct)	101	59.30	18.65	52	52.08	21.19	2.17*
Short-term Capacity (Span length)	116	2.99	0.64	53	2.81	0.68	1.66†
Processing Speed							
Encoding speed – (trials to criterion)	113	8.70	4.12	51	11.47	8.50	2.81**
Reaction time baseline – VExP (ms)	100	225.36	35.30	49	229.72	33.54	.72
Reaction time post baseline – VExP (ms)	105	241.28	34.46	51	236.67	31.00	.81
Representational Competence							
Cross-Modal (% Novelty)	112	49.48	5.14	51	48.05	4.83	1.68†
Anticipations –VExP (%)	105	15.72	11.08	51	14.03	10.05	.92
Attention							
Mean look duration (composite^{a})	118	-0.10	0.58	54	0.19	0.79	2.73**
Shift rate (composite^{a})	118	0.07	0.72	54	-0.15	0.70	1.82†
Mental Development							
Bayley MDI	108	86.02	14.01	54	80.70	17.60	2.09*

Note. VPC = Visual Paired-Comparison Task; VExP = Visual Expectation Paradigm

[a] Mean of standardized values.

† $p \leq 0.10$.

* $p \leq .05$.

** $p \leq .01$.

Table 2

Preterm/Full-Term Differences: 36-months

	Full-terms			Preterms			
	N	**M**	**SD**	**N**	**M**	**SD**	**t-test**
Memory							
Immediate Recognition (composite)							
Rose VPC (% Novelty)	108	58.47	6.34	50	55.52	6.53	2.70**
Fagan VPC (% Novelty)	108	61.69	5.78	48	59.66	6.45	1.95*
Delayed Recognition (% Novelty)	96	61.89	7.61	44	62.76	6.74	.65
Recall – elicited imitation (% Correct)	99	76.83	16.32	49	69.13	20.59	2.47**
Short-term Capacity (Span length)	109	4.22	1.02	49	4.26	1.00	.26
Processing Speed							
Encoding speed – (trials to criterion)	101	18.57	10.66	48	23.20	11.52	2.42*
Reaction time baseline – VExP (ms)	96	209.12	31.43	45	207.13	30.12	.36
Reaction time post baseline – VExP (ms)	106	229.48	30.79	46	232.84	33.97	.60
Representational Competence							
Cross-Modal (% Novelty)	105	48.28	4.36	48	46.79	5.81	1.76†
Anticipations –VExP (%)	106	20.68	12.45	46	17.70	11.53	1.38
Attention							
Mean look duration (composite[a])	109	-0.11	.55	50	.21	.68	3.11**
Shift rate (composite[a])	109	.10	.76	50	-.22	.58	2.58**
Mental Development							
Bayley MDI	106	89.61	13.45	50	85.00	11.56	2.09*

Note 1. VPC = Visual Paired-Comparison Task; VExP = Visual Expectation Paradigm

Note 2. Children took longer to reach criterion than at 24 months because familiarization times were shorter and the criterion was more stringent

[a] Mean of standardized values.

† $p \leq 0.10$.

* $p \leq .05$.

[**] $p \leq .01$.

Table 3

Within and cross-age correlations of measures at 24 and 36 months (partialed for birth status)

	Memory				*Processing Speed*			*Representational Competence*		*Attention Development*		*MDI*
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
							Within-age Correlations					
1. Immediate Recognition (composite)		.27**	.01	.10	-.11	-.09	.03	.09	.01	-.06	.07	.38***
2. Delayed Recognition	.16†		.07	-.09	-.09	-.03	-.03	-.08	-.06	.02	-.02	.20*
3. Recall (elicited imitation)	.20*	.21*		.05	-.17*	-.08	-.04	-.05	-.01	-.09	-.01	.31***
4. Short-term capacity (span)	.05	-.04	-.05		.08	-.12	.06	.07	-.04	.01	.02	.02
5. Encoding speed (Continuous Familiarization)	-.15†	-.22*	-.05	.02		-.01	-.09	-.04	.01	.24**	-.23**	-.26***
6. Baseline RT (VExP)	-.16†	-.26**	-.03	.05	.13		.52***	.17*	-.25**	.20*	-.16†	-.07
7. Postbaseline RT (VExP)	-.14†	-.03	-.04	.01	.01	.43***		.04	-.26***	.01	-.07	-.07
8. Cross-modal transfer)	.01	-.04	.01	.02	.03	.10	-.10		-.09	.07	-.10	.25**
9. Anticipations (VExP)	.15†	-.02	.06	-.12	-.09	-.31***	-.30***	.03		-.18*	.24**	-.07
10. Mean look duration (composite)	-.08	-.11	-.18*	.11	.24**	.23**	.33***	-.02	-.22**		-.80***	-.03
11. Shift rate (composite)	.04	.07	.07	-.13	-.38***	-.19*	-.28***	.03	.25**	-.78***		-.00
12. Bayley MDI	.30***	.14	.44***	-.02	-.16*	.02	-.11	.25**	.03	-.17*	.12	
						Cross-age Correlations						
	.39***	.24**	.43***	.19*	.22**	.43***	.53***	.21**	.39***	.42***	.43***	.76***

Note 1 – Correlations are computed using pair-wise deletion. Within-age correlations at 24 months are shown above the diagonal; those at 36 months are below the diagonal. N = 141-169

Note 2. VPC = Visual Paired-Comparison Task; VExP = Visual Expectation Paradigm.

[†] $p \leq 0.10$.

[*] $p \leq .05$.

[**] $p \leq .01$.

Table 4

Simultaneous Multiple Regressions: Prediction of MDI from Concurrent Information Processing at 24- and 36-Months

	24-Month Regression			36-Month Regression		
Predictors	**sr^2**	**β**	**t**	**sr^2**	**β**	**T**
Birth Status	.00	-.03	.44	.00	-.03	.36
Immediate Recognition	.09	.32	4.43^{***}	.04	.23	3.11^{**}
Delayed Recognition	.01	.09	1.31	.00	.01	.14
Recall	.07	.27	3.91^{***}	.11	.35	4.84^{***}
Encoding Speed	.02	-.16	2.23^{*}	.01	-.09	1.30
Cross-Modal	.04	.21	3.12^{**}	.05	.23	3.38^{***}
Look Duration	.00	.04	.57	.00	-.07	-.91
	$R^2 = .32$			$R^2 = .31$		
	$F(7,154) = 10.35^{***}$			$F(7,138) = 9.66^{***}$		

† $p \le 0.10$.

[*] $p \le .05$.

[**] $p \le .01$.

[***] $p \le .001$.

Table 5

Correlations of Infant and Toddler Measures of Information Processing with One Another and Toddler MDI (partialed for birth status)

Information Processing Measures	**Infant/Toddler Information Processing**	**Infant Information Processing with MDI**	**Toddler Information Processing with MDI**
Immediate Recognition (composite)	$.33^{***}$	$.33^{***}$	$.41^{***}$
Delayed Recognition	$.29^{***}$	$.20^{**}$	$.24^{**}$
Recall (elicited imitation)	$.26^{***}$	$.29^{***}$	$.44^{***}$
Short-term capacity (span)	.11	.09	.01
Encoding speed (Continuous Familiarization)	$.20^{**}$	$-.18^{*}$	$-.23^{**}$
Baseline RT (VExP)	$.29^{***}$	-.03	-.07
Postbaseline RT (VExP)	$.35^{***}$	-.05	-.12
Cross-modal transfer	$.18^{*}$	$.35^{***}$	$.30^{***}$
Anticipations (VExP)	$.25^{***}$	-.12	-.01
Mean look duration (composite)	$.37^{***}$	-.07	-.12
Shift rate (composite)	$.33^{***}$	$.14^{\dagger}$	.06

Note 1 –The 7- and 12-month scores were averaged to create the *Infant Scores*; the 24- and 36-month scores were averaged to create the *Toddler Scores.* *N* = 159-200 for column 1, *N* = 162-170 for column 2, and *N* = 153-170 for column 3.

Note 2. VPC = Visual Paired-Comparison Task; VExP = Visual Expectation Paradigm.

$^{\dagger}p \leq 0.10$.

$^{*}p \leq .05$.

$^{**}p \leq .01$.

$^{***}p \leq .001$.

Table 6

Multiple Regressions Predicting Toddler MDI from Infant and Toddler Information Processing

	Infant Predictors			Toddler Predictors		
Information Processing Measures	**sr^2**	**β**	**t**	**sr^2**	**β**	**T**
Birth Status	.00	.07	.91	.01	-.08	1.24
Immediate Recognition	.06	.26	3.59^{***}	.07	.31	4.45^{***}
Delayed Recognition	.00	.05	.78	.00	.07	1.02
Recall	.04	.20	2.88^{**}	.11	.35	5.42^{***}
Encoding Speed	.00	-.04	.55	.01	-.12	$1.83^{\dagger}$
Cross-Modal	.09	.31	4.55^{***}	.08	.29	4.75^{***}
Look Duration	.00	.00	.06	.00	-.01	.14
	$R^2 = .29$			$R^2 = .42$		
	$F(7,162) = 9.58^{***}$			$F(7,162) = 16.56^{***}$		

[†] $p \leq 0.10$.

[*] $p \leq .05$.

[**] $p \leq .01$.

[***] $p \leq .01$.