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A Cognitive Approach to the Development of Early Language

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Abstract

A controversial issue in the field of language development is whether language emergence and growth is dependent solely on processes specifically tied to language or could also depend on basic cognitive processes that affect all aspects of cognitive competence (domain-general processes). The present article examines this issue using a large battery of infant information-processing measures of memory, representational competence, processing speed, and attention, many of which have been shown to predict general cognition in a cohort of full-terms and preterms. Results showed that various aspects of infant memory and representational competence (a) related to language at both 12 and 36 months, (b) predicted similarly for the two groups, and (c) predicted 36- month language, independently of birth status, 12-month language, and the 12-month Bayley Mental Development Index. Additionally, the results established predictive validity for the MacArthur 12-month language measure. These findings support a domain-general view of language.

Introduction

Young children learn language at an incredible pace. Infants show a bias for listening to speech from birth(Vouloumanos & Werker, 2007), match phonetic information in the face and voice by 4.5 months (Kuhl & Meltzoff, 1982; Patterson & Werker, 2003), and use transitional probabilities to segment the speech stream by 8 months (Saffran , Aslin, & Newport, 1996). The first signs of word comprehension appear soon after, around 9 months, with the spontaneous production of words starting around 12–13 months (Fenson et al., 1994). Although word growth is initially slow, there is a spurt around 16–18 months and by three years children typically have a vocabulary of hundreds of words.

It is a challenge to understand how infants master language so quickly. Although it has long been clear that language learning depends on social interactions (Mundy, Seibert, Hogan, & Fagan, 1983), as well as phonological and lexical coding, more recently, it has been suggested that language also depends on domain-general cognitive processes (Bloom, 1993; Hollich, Hirsh-Pasek, & Golinkoff, 2000). In this view, rather than being a completely modular system involving processes and rules specific to language alone (Pinker, 1994), language is seen as drawing on a set of processes shared with other realms of cognition (Bates, 1994; Fernald,

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Perfors, & Marchman, 2006; Hollich et al., 2000). Although the literature with school-aged children and adults has begun to provide evidence of the contribution of processes such as attention, learning, and memory to language skills (Baddeley, Gathercole, & Papagno, 1998; Cowan, Nugent, Elliot, Ponomarev, & Saults, 1999), there is scant information on the role of these processes in emergence of language.

Meanwhile, work on infant cognition has begun to show that information processing abilities can be isolated in the first year of life and that they are linked to later general cognitive outcomes. For example, using measures from a battery of infant tasks assessing performance in four specific areas -- memory, processing speed, attention, and representational competence -- Rose and her colleagues identified basic abilities in the first year of life that are structurally distinct (Rose, Feldman, & Jankowski, 2004, , 2005b), sensitive to deficits associated with preterm birth, a risk factor for later cognitive deficits (Rose, Feldman, & Jankowski, 2001a, , 2002, , 2005a), and related to later mental ability (Rose, Feldman, Jankowski, & Van Rossem, 2005, , 2007). Moreover, they were able to model the pathways by which the infant cognitive abilities influenced each other and subsequent mental development (Rose, Feldman, Jankowski et al., 2005; Rose et al., 2007).

If the domain-general theory holds, it would be expected that the information processing measures from the Rose et al. battery would also contribute to the emergence and development of language. Below we provide a brief overview of the measures in each area and their relevance to language.

Memory

Memory is vital for accruing all forms of knowledge, including language. While there are multiple memory systems with diverse time courses and diverse neurological substrates (Nelson, 1995), our battery included four types of visual memory (all dependent on the medial temporal lobe): immediate visual recognition memory, delayed recognition, short-term memory, and recall.

Infants who have better memory can be viewed as more adept at encoding, storing, consolidating and retrieving representations of objects and events. These skills are fundamental to language development. Infants with better recognition and recall memory are likely to produce memory traces that are highly discriminable and persistent and, as a consequence, more readily available to be linked to their verbal referents. By contrast, infants with limitations in recognition and recall are likely to need more repetitions of these linkages to reach the same level of proficiency, resulting in slower rates of vocabulary growth. Similarly, infants with better short term memory will be able to hold more information in mind, and thus have an advantage in segmenting the auditory stream into meaningful units (words and phrases).

Studies concerned with the relation of infant memory to language have focused almost exclusively on visual recognition memory, and this type of memory has been shown to correlate with assessments of language proficiency from toddlerhood to adulthood. In particular, better visual recognition memory is related to better comprehension and gestural communication in toddlers (Heimann et al., 2006), better receptive and expressive language in the preschool years (Fagan & McGrath, 1981; Rose, Feldman, Wallace, & Cohen, 1991; Thompson, Fagan, & Fulker, 1991) and the school years (Fagan & Detterman, 1992; Rose & Feldman, 1995; Rose, Feldman, & Wallace, 1992), and better comprehension in adults (Fagan, Holland, & Wheeler, 2007). Additionally, impaired visual recognition memory has been found in infants with a family history of specific language impairment (Choudbury, Leppanen, Leevers, & Benasich, 2007).

Studies examining the relation of other forms of infant memory to early language are rare. Only one study we know of examined the relation of infant recall to language proficiency. That study found recall memory, assessed at 9 months, was related to gestural communication (but not comprehension) at 14 months (Heimann et al., 2006). Although studies with older children have consistently found that both short- term and working memory are also related to language (Cowan et al., 1999; Gathercole & Pickering, 2000; Gathercole, Willis, Emslie, & Baddeley, 1992), to our knowledge, there are no infant studies in this area.

Processing speed

Processing speed is often considered to be the central limiting factor accounting for performance differences on a wide variety of cognitive tasks in childhood and adolescence (Hale, 1990; Kail, 1991). Faster processing speed can influence language development directly, by allowing operations to be performed more rapidly, and indirectly, by increasing the functional capacity of working memory. It is reasonable to assume that limitations in processing speed would make it difficult to keep up with the audio stream, and thus interfere with building up lexical and grammatical representations essential for language development (Leonard et al., 2007).

Two types of speed were included in our infant battery: psychomotor speed and encoding speed. Psychomotor speed, which captures the ocular speed or reaction time (RT) of orienting to predictable and unpredictable events, was assessed using the visual expectation paradigm (VExP; Canfield, Smith, Brezsnyak, & Snow, 1997; Haith, Hazan, & Goodman, 1988; Reznick, Chawarska, & Betts, 2000; Rose, Feldman, Jankowski, & Caro, 2002; Wentworth & Haith, 1992). Encoding speed, which captures the rapidity of assimilating information about a target, was assessed using the ‘continuous familiarization’ task (Rose, Feldman, & Jankowski, 2002; Rose, Feldman, Jankowski et al., 2002; Rose, Futterweit, & Jankowski, 1999).

Although it has been known for some time that rapid auditory processing is impaired in school-aged children with specific language impairments (Miller, Kail, & Leonard, 2001; Tallal, Stark, & Mellitis, 1985), and in infants with a family history of language impairment (Choudbury et al., 2007), little is known about the role of processing speed in infants’ acquisition of language (but see Fernald et al., 2006).

Attention

Attention is multi-faceted, and often characterized as including the ability to engage, maintain, disengage, and shift focus (Mirsky, 1996; Posner & Petersen, 1990; Posner & Raichle, 1994). Infants with better attention are likely to acquire language more quickly because they would be better able to follow others gazes, engage in bouts of joint attention, and track the referents of others’ communications. These attentional skills in a social context might lead to larger receptive and productive vocabularies.

Two interrelated aspects, having to do with the way infants distribute or deploy attention were included in the present battery: look duration and shift rate. Short looks and more frequent shifts of gaze are thought to reflect either more rapid encoding and/or greater facility at disengaging attention (Colombo, 1993; Colombo, Mitchell, Coldren, & Freeseman, 1991; Freeseman, Colombo, & Coldren, 1993; Frick, Colombo, & Saxon, 1999; Jacobson, Jacobson, Sokol, Martier, & Ager, 1993). Higher shift rates are believed to reflect, additionally, a more active comparison of targets (Rose et al., 2001a; Rose, Feldman, McCarton, & Wolfson, 1988; Ruff, 1975). Both change dramatically over the first year of life with look durations becoming shorter and shift rates becoming faster (Colombo, Mitchell, O’Brien, & Horowitz, 1987; Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004; Frick et al., 1999; Rose et al., 2001a).

Two recent studies have examined the relation of infant attention to language and their results have been contradictory. One found better language to be associated with decreasing look durations (Colombo et al., 2004; Colombo et al., in press), while the other found better language to be associated with longer look durations (Arterberry, Midgett, Putnick, & Bornstein, 2007).

Representational Competence

We have used the term ‘representational competence’ to refer to the ability to extract commonalties from experiences and represent them abstractly or symbolically. Representational and symbolic abilities have long been considered necessary for language development, where arbitrary relations must be established between words and their referents.

Our infant battery included four tasks thought to assess representational ability: tactual-visual cross-modal transfer, where information about shape is extracted from one modality and applied to another (Rose & Feldman, 1995; Rose, Feldman, Futterweit, & Jankowski, 1997; Rose, Feldman, & Wallace, 1988); anticipation of future events (from the VExP task), which necessitates abstracting a rule governing changes in location from a fast-paced sequence of pictures (Canfield et al., 1997; Rose, Feldman, Jankowski et al., 2002); object permanence, which involves keeping in mind the existence and location of a hidden object (Piaget, 1950); and symbolic play, which requires using one object to represent another in pretense (e.g., ‘drinking’ from a block of wood, where the block represents a ‘cup’) (Damast, Tamis-Lemonda, & Bornstein, 1996; Tamis-LeMonda & Bornstein, 1990). All have in common the representation of things (or locations) that are not immediately available to the senses.

There is a considerable amount of work relating symbolic play (Fein, 1981; McCune-Nicolich, 1981; Tamis-LeMonda & Bornstein, 1990; Tamis-LeMonda, Damast, & Bornstein, 1994; Ungerer & Sigman, 1984) and object permanence (Corrigan, 1978; Tomasello & Farrar, 1984) to language proficiency. However, less is known about the relation of the other two aspects of infant representational competence to language. Anticipations have not been studied at all in this regard, and, aside from two reports froma single cohort (Rose &Feldman, 1995; Rose et al., 1992), little work has been done with respect to tactual-visual cross-modal transfer. A possible mechanism explaining the connection between tactual – visual transfer and language is offered by the recent discovery of cortical multisensory neurons, which respond to sight, sound, and touch (Wallace, Carriere, Perrault, Vaughan, & Stein, 2006; Wallace, Ramachandran, & Stein, 2006), which suggests that the ability to transfer information across modalities may be independent of the specific modalities involved.

Present Study

The present study addresses a theoretically important issue about the development of language – namely, whether those processes that foster its growth are domain-general in character. Few previous studies have addressed this issue in infancy and those that have done so have looked at only one or very few infant abilities at a time. Additionally, most have related infant abilities either to contemporaneous language or to later language, but not both. The present study, by contrast, uses an extensive battery of infant abilities, including some not previously studied in relation to language, and examines both concurrent and predictive relations. The battery was developed in the course of a longitudinal study of cognitive development from infancy to three years (Rose et al., 2004; Rose, Feldman et al., 2005b). It has been shown to provide a differentiated and theoretically meaningful view of infant’s cognitive abilities and to predict general cognitive ability at ages 2 and 3 years (Rose, Feldman, Jankowski et al., 2005). By following children longitudinally we will be able to assess the role of these domain-general processes not only in the emergence of language but also in its subsequent development.

Another unique aspect of the present study is that the longitudinally followed cohort includes groups that differ with respect to biological risk – namely, preterms and full-term controls (group-matched on age, gender, and SES). Several studies have found language deficits in preterm or low-birthweight children in the preschool period, primarily in receptive language and, to a lesser extent, in expressive language (Caravale, Tozzi, Albino, & Vicari, 2005; Scottish Low Birthweight Study Group, 1992). However, relatively few studies have examined the language capabilities of preterms at the earliest stages of language development (Briscoe, Gathercole, & Marlow, 2001) and, to our knowledge, none have examined the cognitive underpinnings of early language in preterms.

An ancillary contribution of the present study will be to provide hitherto unavailable data on the predictive validity of the short form of the MacArthur Communicative Developmental Inventory (CDI/Words and Gestures), a parent report instrument designed for 8 – 18-month-olds (Fenson et al., 2000). Although there is considerable evidence for concurrent and predictive validity for the CDI/Words and Sentences inventories, designed for older children, evidence for the predictive validity of the CDI/Words and Gestures inventory is lacking. Predictive work with this latter version has not been done, in part, because its concurrent validity was called into question when a negative association was found between maternal education and the vocabulary scores reported for 1-year-olds (Feldman et al., 2000). Negative relations are not the norm, and were unexpected, since language development is often delayed in children from such households; moreover, negative relations have not been found between CDI scores and maternal education at older ages (Pan, Rowe, Spier, & Tamis-Lemonda, 2004). The current study offers the opportunity to re-examine the relation of the Words and Gestures version of the CDI to maternal education, and to examine its predictive validity.

Overall then, the present work, part of a longitudinal, prospective study of preterms and full-terms, uses an extensive battery of infant information processing measures from 12 months to examine whether and how early language might be affected by memory, representational competence, processing speed and attention in infancy, and whether relations between these cognitive abilities and language are similar for preterms and full-terms. In addition, we will determine whether these infant information processing abilities have any unique role in later language outcome (over and above that of concurrent language). These results will be relevant to the role of domain-general processes in the emergence and growth of language.

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. The present report included those infants (N = 182; 56 preterms and 126 full-terms) who had data on tasks of information processing at 12 months.

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 recruits 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).

Of the 56 preterms seen at 12 months, 50 returned at 36 months (89.3%); of the 126 full-terms seen at 12 months, 110 returned at 36 months (87.3 %). 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—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). English was the only, or the primary language spoken in the home for 89.8% of the sample. The remainder was solely (3.2%) or primarily (7.0%) Spanish- speaking. For further details on medical and background characteristics see (Rose et al., 2001a).

Procedure

The measures considered here include those assessing different types of memory (immediate and delayed recognition, recall, working memory), representational competence (cross-modal transfer, object permanence, symbolic play, anticipations), processing speed (psychomotor RT, encoding speed) and attention (look duration, shift rates) at 12 months, developmental outcome at 12 months (Bayley performance), and several aspects of language and early communication at 12- and 36-months.

Information Processing (12 Months)

Memory: ***Visual Recognition memory:*** Recognition memory was assessed with two visual paired-comparison (VPC) 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 lab, was comprised of 5 face problems (10 s familiarization) and 4 pattern problems (3 s familiarization). The test periods lasted for 10 s (Rose et al., 2001a). The other task, the Fagan Test of Infant Intelligence (FT11;(Fagan & Sheperd, 1989), comprised of 10 face problems, had a similar, though somewhat more varied, 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)

Short-term Memory Capacity: This aspect of memory was assessed with a span task, which consisted of 10 problems, arranged in spans of 1, 2, 3, and 4. For a span of 1, the procedure was similar to that described above for the visual paired-comparison 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.

Spans were presented in ascending order. The stimuli were colorful, attractive, 3-dimensional objects. On familiarization trials, an object was displayed until the infant accumulated 3 s of looking time. On test, paired stimuli were presented for 10 s (For further details, see (Rose, Feldman, & Jankowski, 2001b). *Span Length* was measured by the highest number of items ‘recognized’ (defined by a novelty score > 55%) from any of the four spans.

Reliability estimates are not available for this measure, although short-term stability over a 2-month period (5 to 7months) was r = .28.

Delayed Recognition: To assess delayed recognition, infants were initially habituated to three objects in succession, using a modified infant-controlled procedure (Diamond, 1990), and then, after a 1-s delay, given a series of test trials in which each habituated object was successively paired with a new one for 10 s. This habituation-test procedure was repeated twice more, with delays of 3 and 5 minutes. The stimuli were colorful, attractive, 3-dimensional objects (similar to those used in the span task). The overall score, computed by averaging novelty scores for each of the 9 problems (3 problems at each of the three delays of 1, 3, and 5 minutes), was used here.

There are no reliability data for this measure.

Recall Memory: Recall memory was assessed with the elicited imitation task (adapted from (Bauer, 2002). Here, the examiner modeled each of three event sequences – make a noisemaker, make a rattle (e.g., place small block on paddle, cover block, shake paddle to create rattle sound), and ring a gong -- three times in succession; after a 15-min delay, the infant was given the props for each sequence, in turn, to reproduce the sequences (for further details, see (Rose, Feldman et al., 2005a). Recall memory, measured by the *Percentage of Target Actions Reproduced* for each event sequence, was averaged over sequences.

Reliability estimates are not available for this measure.

Representational Competence: ***Cross-modal transfer:*** Cross-modal transfer was assessed with a task of tactual-visual transfer, which involves extracting information about shape from one modality and applying it to another (Rose & Feldman, 1995; Rose et al., 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).

Anticipations: The ability to anticipate forthcoming events was measured by the VExP task. Here, infants had to abstract the rule governing changes in location for a fast-paced sequence of pictures (Canfield et al., 1997; Rose, Feldman, Jankowski et al., 2002). In this task, there were 60 trials in which computer-generated images were presented in a predictable right-right-left (RRL) spatio-temporal sequence. Stimulus durations were 500 ms; inter-stimulus intervals were 720 ms (For further details, see Rose, Feldman, Jankowski et al., 2002). Saccades to the upcoming stimulus were considered to be anticipatory, and thus to reflect rule based expectations, if they were initiated before the stimulus could be perceived, that is, before onset or within 200 ms of onset, the minimal time thought to be required to initiate a saccade (Haith et al., 1988). Performance was assessed by the *percentage of anticipatory saccades*.

Test-retest reliability has been reported as *r* = .34 for 3-month-olds tested on two occasions 2–8 days apart; internal consistency (split half) was reported to be *r* = .51 and .52 within sessions (Haith & McCarty, 1990.).

Object Permanence: Object permanence, which involves keeping in mind the location of an object, even though the object is hidden from view (Piaget, 1950), was assessed with the Einstein Scale of Object Permanence (Corman & Escalona, 1969). Here, the infant's ability to retrieve hidden objects after successive hidings is coded into stages: *Stage 3* – recovers an object that has been partially but not fully hidden; *Stage 4*—recovers a completely hidden object, but errs on succeeding trials when the location of the object is changed; *Stage 5* – correctly retrieves a hidden object, but only if its displacement had been visible (e.g., if the object is hidden in the experimenter's hand and then moved to a hiding place, the infant errs by searching for it in the experimenter's hand); *Stage 6* – correctly retrieves objects even after invisible displacements. The infant's score is the *Highest Stage* achieved.

Green's index of consistency was 1.00, indicating that this scale meets Guttman's criterion for a true scale (Corman & Escalona, 1969) and infants are consistent between 75% and 92% of the time across sessions in whether they performed a particular action(Uzgiris & Hunt, 1975).

Symbolic Play: Symbolic play was elicited by modeling increasingly higher complex sequences of pretense actions (adapted from those found in free play, see (Belsky & Most, 1981; Damast et al., 1996; Tamis-LeMonda & Bornstein, 1990) and encouraging the infant to imitate each. The sequences included self- and other-directed actions (child drinks from a toy cup; feeds the doll from a cup); sequencing (child stirs the cup with a spoon and then feeds the doll with the spoon); object substitution (child stirs on block with spoon and then drinks from the block); and vicarious action for others (child feeds the doll and makes eating sounds for the doll). There were 18 levels, with four opportunities to succeed at each; testing terminated when two levels were failed in succession. Performance 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: ***Psychomotor Speed (RT):*** This aspect of processing speed was assessed with reaction time measures from the VExP task (Haith et al., 1988) described above. In addition to the 60 series trials, where the images were presented in a predictable right-right-left (RRL) sequence, the tasks included 10 baseline trials, where the right or left placement was random. All latencies > 200 ms after stimulus onset were scored as RTs (Haith et al., 1988). Performance was indicated by *Mean RT* on baseline trials and *Mean RT* on series trials.

Test-retest reliability has been reported as *r* = .48 for the median RT in 3-month-olds tested on two occasions 2–8 days apart (Haith & McCarty, 1990.).

Encoding Speed: This aspect of speed was assessed with the 'continuous familiarization' task, in which infants view a series of paired photographs, one of which changes across trials. Testing continues until infants show a consistent preference for the new one, defined as four out of five consecutive trials having a novelty score > 55%, but < 100% (thus ensuring some looking to each target in the criterion run), or for the maximum of 36 trials. Encoding speed is measured by *Trials to Criterion*, the trial on which the criterion was met, or 36 if it was not met. (For further details, see (Rose, Feldman, & Jankowski, 2002).

Test-retest reliability over a 2-week interval, obtained for a sample of 5-, 7-, and 9-month-olds, was r = .27, partialed for age (unpublished data).

Attention: ***Look duration:*** One measure of attention was look duration, defined as the mean length of look (in s). Six measures of look duration were drawn from four tasks in the battery: two from the Rose VPC task (familiarization and test), two from the Fagan VPC task (familiarization and test), one from the cross-modal task (test), and one from the continuous familiarization task (all trials). In each case, mean look durations were averaged over all problems in a task (or all trials for continuous familiarization). A composite was formed by standardizing all scores and then averaging them (for further details see (Rose, Feldman et al., 2005b).

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: α = .76.

Shift Rate: A second measure of attention, shift rate, was defined as the number of shifts of gaze between paired targets per s. Four measures of shift rate were drawn from three tasks: two from the Rose VPC task (familiarization and test), one from the cross-modal task (test), and one from the continuous familiarization task (all trials), averaged over problems within each task, and then averaged across tasks to form an overall composite.

The internal consistency coefficient was high for scores in the present study: α = .70.

Developmental level (12 months)—Developmental level was assessed at 12 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.

Rater reliability is checked periodically in our lab and is uniformly greater than *r* = .97.

Language (12 and 36 months)—The short-form of the MacArthur Communicative Developmental Inventory – CDI/Words and Gestures (Fenson et al., 2000) was used to assess emerging language at 12 months. Parents completed the 89-word vocabulary checklist of the CDI/Words and Gestures Inventory (designed for 8 −18 month olds). For each word, they indicated which their child understood (Comprehension) or understood and said (Production). They also selected, from a list of 12 communicative gestures (included in a preliminary version of this instrument), those actions the child understood and produced.

Although the CDI inventories were designed to be self-explanatory, the examiner went through the protocol orally with each parent. In preliminary work, we discovered that many parents misinterpreted the word ‘understand,’ leading them to credit their child with understanding a word if the child had any familiarity with it. (For example, one mother initially stated that her child understood the word ‘lion’ because he had seen lions at the zoo. However, she readily acknowledged that he did not know the word ‘lion’ referred to an actual lion rather than some other object, a tree, for example.) Such misunderstandings were common in this population, but were readily countered when the instructions were elaborated to make clear that understanding involved knowledge of the one-to-one correspondence between word and object (or word and action).

At 36 months, language was assessed with the Peabody Picture Vocabulary Test (PPVT Revised – Form L) (Dunn & Dunn, 1981) and an age-appropriate modification of the ETS test of verbal fluency (Singer, Corley, Guiffrida, & Plomin, 1984). These measures of comprehension and expressive language were chosen because we had used them for an 11-

year follow-up in a previous study and found them to relate to some of the same infant measures used here (Rose & Feldman, 1995). The PPVT, a widely used test of receptive language and comprehension, is a standardized assessment that has a mean of 100 and a standard deviation of 15. Verbal Fluency, a measure of expressive language, was evaluated with a task of category fluency, which assessed the child's facility in word-retrieval from semantically-based networks. In this task, the child was asked to name as many things as he/she could think of in three different categories: (1) things to eat (2) all the animals you know and (3) things that make noise. Thirty seconds was allowed for responses to each part; timing began with the first response. The child's score was the total number of items correctly listed, summed over all three 30-s response periods.

For those infants who were from households that were solely or predominately Spanish speaking, the language tasks were administered in Spanish by an examiner who was fluent in Spanish. (All analyses were repeated, restricted to the 89.8% subsample having English as their sole or primary language. There were no appreciable differences from those reported below.)

Results

Descriptive Statistics

Descriptive statistics for the full-term and preterm groups are presented in Table1. The majority of the 1-year information-processing variables showed significant differences favoring the full-terms, who had better recognition and recall, higher levels of symbolic play and object permanence, shorter look durations and more frequent shifts of gaze between paired stimuli. The full-terms also had higher MDI's. On language measures, full-terms outperformed preterms with respect to gestures at 12 months and comprehension at 36 months; there were no significant differences on the other language measures.

Correlations of 12-month Information-Processing with Language

Correlations between information-processing measures and language measures are presented in Table 2, partialed for birth status. Initially, these correlations were obtained separately for the preterms and full-terms and compared across groups using tests of difference for independent correlations. Only four correlations of the 75 (5 language measures X 14 infant measures + MDI) met the criterion for a significant difference at the .05 level, about the same number that would have been expected by chance. Consequently, data were collapsed across both gender and birth status, as shown in Table 2, and in all further analyses. Birth status was partialed to avoid inflation of the correlations due to mean differences.

In general, better 12-month memory was significantly associated with better language at both 12 months and 36 months. With the exception of short term capacity, all the 12-month memory tasks were related significantly (or nearly so) to one or more aspects of language at each age. Of the various types of memory assessed at 12 months, delayed recall was most consistently related to language, having significant correlations (ranging from .20 to .28) with all the language measures but fluency.

Similarly, better representational competence at 12 months was generally related to better language; with the exception of visual anticipations, most of the 12-month measures for this aspect of infant cognition were significantly associated with one or more aspects of both contemporaneous and later language. Two of these measures – cross-modal transfer and object permanence – had significant correlations ($r \geq .30$) with 3-year language; both also had fairly consistent and substantial correlations with contemporaneous language measures.

By contrast, none of the measures of processing speed or attention related to language at either age.

Correlations Among Language Measures

As shown in Table 3, for the most part, correlations among all language measures, both within and across age, were fairly substantial. It is noteworthy that parent report measures of comprehension and production at 12 months correlated moderately well with standardized or laboratory-based measures of these same two constructs (PPVT and Verbal Fluency) made two years later (r = .29 to .49). The measure of gestural communication from the 12-month CDI was also related to later language, but less strongly.

Regressions

Hierarchical regressions predicting 36-month outcomes were done to establish the variance predicted by (a) infant information processing measures beyond that of birth status, (b) infant language beyond birth status, and (c) individual information processing measures beyond all other measures (birth status and infant language combined). The regressions included only the seven information processing measures that related significantly to at least one of the 36-month language measures.

The results are shown in Table 4 and Table 5, where the change in R^2 indicates the increase in variance predicted by adding successive sets of variables and the cumulative R^2s indicates the total amount of variance predicted. Several statistics are provided from the final equation: the squared semi-partial correlation coefficient, sr^2, which indicates the independent contribution to outcome of each individual predictor when all are simultaneously included in the regression equation; the standardized partial regression coefficients, β, which indicates the change in standard deviation units in the outcome variable associated with a 1 standard deviation increment in the predictor, all else being held constant; and the t-value with its significance level associated with both the sr^2 and β.

Regressions predicting comprehension (PPVT) at 36 months

Predicting from infant information processing—The first model in Table 4 shows that, over and above birth status, about 31% of the variance in the PPVT was predicted by the 12-month battery of information processing measures. Three variables are uniquely predictive independently of all others, namely, recognition memory (as assessed in the Rose task), recall, and cross-modal transfer. The total amount of variance predicted by birth status and the infant information processing measures was 34%.

Predicting from infant language—The second model in Table 4 shows that the three 12-month parent-report measures of language from the CDI accounted for 26% of the variance in PPVT, over and above birth status. Two of the language measures, comprehension and production, were uniquely predictive. The total amount of variance predicted by birth status and the three 12-month measures of language was 29%.

Predicting from both infant language and infant information processing—The third model in Table 4 shows that, even with birth status and infant language controlled, the 12-month information processing measures independently contribute about 15% to PPVT. Moreover, the same three processing measures continue to contribute uniquely to prediction, namely, recognition memory (Rose task), recall, and cross-modal transfer. The total amount of variance predicted by birth status and 12-month measures of information processing and language combined was 44%.

Regressions predicting expression (Verbal Fluency) at 36 months

Predicting from infant information processing—The first model in Table 5 shows that, over and above birth status, about 17% of the variance in Verbal Fluency was predicted by the

12-month battery of information processing measures. Here, only one variable was individually predictive independently of all others, namely, cross-modal transfer. The total amount of variance predicted by birth status and the infant information processing measures was 18%.

Predicting from infant language—The second model shows that the three 12-month parent-report measures of language from the CDI accounted for12% of the variance in Verbal Fluency above and beyond birth status. Of these three CDI measures, comprehension and production were both uniquely predictive. The total amount of variance predicted by birth status and the three 12-month language measures was 13%.

Predicting from both infant language and infant information processing—The third model shows that, even with birth status and the three infant language measures controlled, the 12-month information processing measures independently contribute about 10% to Verbal Fluency. Again, only cross-modal transfer contributed uniquely to prediction. The total amount of variance predicted by birth status and 12-month measures of information processing and language combined was 23%.

Ancillary analyses

Controlling for 12-month MDI—The hierarchical regressions of Table 4 and Table 5 (Model 3) were repeated, including an additional control measure to represent overall developmental status, namely, 12-month MDI. Even with this additional control, the set of information processing measures continued to contribute independently to the prediction of 36-month PPVT (14 % of the variance, $p < .001$) and verbal fluency (8%, $p = .067$). Moreover, in both cases, the same 12-month information processing measures remained significant in the final equation: For PPVT, recognition memory – rose ($\beta = .23$, $p < .01$), recall ($\beta = .17$, $p = .05$), and cross-modal transfer ($\beta = .29$, $p < .01$); for Verbal Fluency, cross-modal transfer ($\beta = .20$, $p < .05$). MDI had no significant independent effect in either equation.

Discussion

The present study examined the question of whether basic cognitive processes that are not specific to language, but domain-general, play a role in the emergence and development of language ability. To do this, four aspects of infant information processing were assessed at 12 months – memory, representational competence, processing speed, and attention – and related to language, concurrently and predictively. Language was assessed at 12 months with a parent-report measure, the short form of the CDI/Words and Gestures Inventory, and at 36 months with the PPVT and Verbal Fluency. Although some of the infant measures have been used in previous research examining the cognitive antecedents of language, studies of this type are somewhat limited, and none have examined measures from multiple cognitive areas at once, a strategy that enables evaluation of the relative importance of each.

There were five main findings. First, several measures of infant information processing from two of the domains—memory and representational competence— were related to language, both concurrently and predictively. Second, although preterms had lower scores than full-terms on a number of measures, the relations between information processing and language proficiency was similar for both groups. Third, the 12-month information processing measures predicted language at 36 months independently of birth status, 12-month language, and 12-month Bayley MDI. Fourth, three of the infant information processing measures (recognition memory, recall, and cross-modal transfer) predicted later language independently of one another. Fifth, this study provided the first evidence of the predictive validity of the short form of the CDI/Words and Gestures.

The memory measures that were related to language included recognition (both immediate and delayed) and recall. All related modestly, with correlations generally in the .30's. These findings corroborate previous work which has linked infant recognition memory to comprehension through adulthood. They show that this form of memory is also predictive of expressive language, and reveal, for the first time, that infant recall memory has strong and consistent relations with later language extending at least to three years. Surprisingly, our measure of short-term memory did not relate to language, despite the extensive literature supporting such a relation in older children (Baddeley et al., 1998; Gathercole et al., 1992).

As noted earlier, infants who have better memory are more likely to have memory traces that are highly discriminable and persistent, increasing the probability that words would be semantically linked to them. It is not immediately clear, however, why recognition and recall tended to impact language independently. One possible reason might be the differences in the level of perceptual support involved. It is easier to evoke a representation where the object is present to serve as a cue than in recall, where the object is absent. A second possible reason is that the recall task involves a social component that is absent in recognition tasks. In the recall task, the infants need to imitate action sequences demonstrated by the experimenter; success depends upon the infants' having a desire to imitate the actions of others.

Because language would seem to be more dependent on auditory than visual memory, it might seem surprising that visual measures would be related to language. However, a recent study of recognition memory found parallel effects in the visual and auditory modalities for the number of items to be remembered, retention interval, and serial position (Visscher, Kaplan, Kahana, & Sekuler, 2007). These findings suggest that recognition memory abilities may be general rather than modality specific.

Three measures of representational competence were related to language: tactual-visual cross-modal transfer, symbolic play, and object permanence. As was the case for memory, relations were modest; again, generally in the .30's. These measures involve the ability to abstract and manipulate fairly complex representations – matching tactual impressions to visual ones, performing actions in pretend scenarios, and understanding that objects hidden from view still exist. They all share with language the mental representation of objects absent any immediate visual support.

Our findings for symbolic play complement an extensive body of work showing its relation to language (Fein, 1981; McCune-Nicolich, 1981; Tamis-LeMonda & Bornstein, 1990; Tamis-Lemonda, Shannon, Cabrera, & Lamb, 2004). Advances in symbolic play, using one object to represent another, could pave the way for advances in linguistic representations, using words to represent objects. Similarly, infants who are able to understand that objects continue to exist even when out of sight, as evidenced by their advances in the object permanence scale, are more likely use words to refer to objects that are absent. The findings of relations between infant tactual-visual cross-modal performance and language ability are in line with earlier results from our lab (Rose et al., 1992). These results have recently been confirmed by findings from two large samples of preschoolers, where performance on a similar cross-modal task was found to be related to concurrent measures of phonological awareness and language comprehension (Giannopulu, Cusin, Escolano, & Dellatolas, in press). As noted earlier, the ability to transfer information across modalities may be independent of the specific modalities involved, a possibility supported by the recent finding of cortical multisensory neurons, which respond to sight, sound, and touch (Wallace, Carriere et al., 2006; Wallace, Ramachandran et al., 2006).

Measures from the other two domains, processing speed and attention, were not related to either measure of language. Although the literature relating measures from either domain to language is, as noted earlier, sparse, the present results are in accord with the only two studies previously conducted. A study by Fernald and colleagues (Fernald et al., 2006) used one of the same measures used here, namely, RT from the VExP task and, like the present study, found that it did not relate to language. Similarly, Colombo and colleagues (Colombo et al., 2004) used one of the same measures of attention used here, namely, mean look duration; again, like the present study, they found that mean look duration per se did not correlate with language. However, both authors did find associations between language and speed or attention using measures of age-related change. Colombo et al. (2004), for example, found that infants who showed an age appropriate decline in mean look duration from the earlier to the later part of the first year had better scores on a language factor in the second year. And Fernald et al. found that word recognition speed at 25 months was related to the rate of vocabulary growth over the second year of life. Moreover, additional measures of these two elementary cognitive abilities may also prove fruitful in future research, such as measures of temporal processing speed (Tallal, Stark, & Mellitis, 1985), or measures of focused or joint attention (Ruff & Lawson, 1990).

The present study is the first, to our knowledge, to examine the predictive value of the short form of the CDI/Words and Gestures, designed for 8-to 16-month olds (Fenson et al., 2000). In the present study, 12-month measures of comprehension and production from this inventory correlated significantly with 36-month performance on the PPVT and a test of verbal fluency ($r = .29$ to $.49$), thus showing predictive validity over a 2 year delay. These findings support those obtained with the toddler form of the CDI (Feldman et al., 2005; Pan et al., 2004; Reese & Read, 2000). Predictive validity for the infant form of this parent-report instrument had been in question for two reasons. First, the original versions of the CDI were standardized on a middle and upper class sample, and it was not clear they would be applicable to a largely minority and/or racially and economically diverse sample (like the present one). Second, Feldman and colleagues (Feldman et al., 2000) found a negative association between maternal educational level and parent report, suggesting that mothers with less education over-report their children's language abilities in the first year. However, in the present study, correlations between maternal education and infants' language were positive, as one would expect, ($r = .20$, $p =.01$, $r = .22$, $p < .01$, and $r = .11$, $p >.10$ with comprehension, production, and gestures, respectively). Thus, the previous finding of an inverse relation between social class and parent report does not appear to be robust. Moreover, as noted earlier (see Procedure section), preliminary work in our lab had suggested that over-reporting at 1 year is often due to adults' equating infant 'understanding' with a general familiarity with the word or action, rather than with the infant's ability to recognize the word as a label for a particular object or action. Once this misunderstanding was addressed, over-reporting did not appear to be a major problem.

Finally, it should be noted that with respect to language, the effects of birth status were mixed. Preterms were reported to use fewer gestures at 12 months and were found to have lower PPVT scores at 36 months, but on other measures, there were no group differences. This mixed picture is consistent with the literature. In any event, the relations between measures within and across age were similar for both groups.

In sum, the findings from the present study suggest that basic visually-based cognitive processes in infancy contribute to the development of early language and its growth from 1 to 3 years. These results support the theoretical notion that the cognitive bases of language are not solely proprietary, but instead may be of a domain-general nature.

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References

Arterberry ME, Midgett C, Putnick DL, Bornstein MH. Early attention and literacy experiences predict adaptive communication. First Language 2007;27:175–189.

Baddeley AD, Gathercole SE, Papagno C. The phonological loop as a language learning device. Psychological Review 1998;105:158–173. [PubMed: 9450375]

Bates E. Modularity, domain specificity and the development of language. Discussions in Neuroscience 1994;X:135–156.

Bauer PJ. Long-term recall memory: Behavioral and neuro-developmental changes in the first 2 years of life. Current Directions in Psychological Science 2002;11(4):137–141.

Bayley, N. The Bayley Scales of Infant Development. San Antonio, Texas: Psychological Corporation; 1993.

Belsky J, Most RK. From exploration to play: A cross sectional study of infant free play behavior. Developmental Psychology 1981;71:630–639.

Bloom, L. The transition from infancy to langauge. New York: Cambridge University Press; 1993.

Briscoe J, Gathercole SE, Marlow N. Everyday memory and cognitive ability in children born very prematurely. Journal of Child Psychology and Psychiatry 2001;42(6):749–754. [PubMed: 11583247]

Canfield RL, Smith EG, Brezsnyak MP, Snow KL. Information processing through the first year of life. Monographs for the Society for Research in Child Development 1997;62(2 Serial No 250)

Caravale B, Tozzi C, Albino G, Vicari S. Cognitive development in low risk preterm infants at 3–4 years of life. Archives of Disease in Childhood - Fetal Neonatal Edition 2005;90:F474–F479.

Choudbury N, Leppanen PHT, Leevers HJ, Benasich AA. Infant information processing and family history of specific language impairment: converging evidence of RAP deficits from two paradigms. Developmental Science 2007;10:213–236. [PubMed: 17286846]

Colombo, J. Infant cognition: Predicting later intellectual functioning. Newbury Park: Sage; 1993.

Colombo J, Mitchell DW, Coldren JT, Freeseman LJ. Individual differences in infant visual attention: Are short lookers faster processors or feature processors? Child Development 1991;62:1247–1257. [PubMed: 1786713]

Colombo J, Mitchell DW, Horowitz FD. Infant visual attention in the paired-comparison paradigm: Test-retest and attention-performance relations. Child Development 1988;59:1198–1210. [PubMed: 3168636]

Colombo J, Mitchell DW, O'Brien M, Horowitz FD. The stability of visual habituation during the first year of life. Child Development 1987;58:474–487. [PubMed: 3829788]

Colombo, J.; Shaddy, DJ.; Blaga, OM.; Anderson, CJ.; Kannass, KN.; Richman, WA. Early attentional predictors of vocabulary in childhood. In: McCardle, CJP.; Freund, L., editors. Measuring language in infancy. Mahwah, NJ: Erlbaum; (in press).

Colombo J, Shaddy DJ, Richman WA, Maikranz JM, Blaga OM. The developmental course of habituation in infancy and preschool outcome. Infancy 2004;5:1–38.

Corman HH, Escalona SK. Stages of sensorimotor development: A replication study. Merrill-Palmer Quarterly 1969;15:351–361.

Corrigan R. Language development as related to stage 6 object permanence. Journal of Child Language 1978;5:173–190.

Cowan N, Nugent LD, Elliot EM, Ponomarev I, Saults S. The role of attention in the development of short-term memory: Age differences in the verbal span of apprehension. Child Development 1999;70:1082–1097. [PubMed: 10546336]

Damast AM, Tamis-Lemonda CS, Bornstein MH. Mother-child play: Sequential interactions and the relation between maternal beliefs and behaviors. Child Development 1996;67:1752–1766. [PubMed: 8890505]

Diamond, A. Rate of maturation of the hippocampus and the developmental progression of children's performance on the delayed non-matching to sample and visual paired comparison tasks. In: Diamond, A., editor. Development and neural bases of higher cognitive functions: Vol. 608. Annals of the New York Academy of Sciences. New York: Academic Press; 1990. p. 394-426.

Dunn, LM.; Dunn, LM. Peabody Picture Vocabulary Test. Vol. Third Edition. Circle Pines, MN: American Guidance Service; 1981. PPVT-Revised

Fagan JF, Detterman DK. The Fagan Test of Infant Intelligence: A technical summary. Journal of Applied Developmental Psychology 1992;13:173–193.

Fagan JF, Holland CR, Wheeler K. The prediction, form infancy, of adult IQ and achievement. Intelligence 2007;35:225–231.

Fagan JF, McGrath SK. Infant recognition memory and later intelligence. Intelligence 1981;5:121–130.

Fagan, JF.; Sheperd, P. The Fagan Test of Infant Intelligence. Cleveland, Ohio: Infantest Corp; 1989.

Fein G. Pretend play in childhood: an integrative view. Child Development 1981;52:1095–1118.

Feldman HM, Dale PS, Campbell TF, Colborn DK, Kurs-Lasky M, Rockette HE, Paradise JL. Concurrent and predictive validity of parent reports of child language at ages 2 and 3 years. Child Development. 2005

Feldman HM, Dollaghan CA, Campbell TF, Lasky M, Janosky JE, Paradise JL. Measurement properties of the MacArthur Communicative Development Inventories at ages 1 and 2 years. Child Development 2000;71:310–322. [PubMed: 10834466]

Fenson L, Dale PS, Reznick JS, Bates E, Thal D, Pethick S. Variability in early communicative development. Monographs for the Society for Research in Child Development 1994;59(Serial No 242)

Fenson L, Pethick S, Renda C, Cox JL, Dale PS, Reznick JS. Short-form versions of the MacArthur Communicative Developmental Inventories. Applied Psycholinguistics 2000;21:95–115.

Fernald A, Perfors A, Marchman VA. Picking up speed in understanding: Speech processing efficiency and vocabulary growth across the 2nd year. Developmental Psychology 2006;42:98–116. [PubMed: 16420121]

Freeseman LJ, Colombo J, Coldren JT. Individual differences in infant visual attention: Four-month-olds' discrimination and generalization of global and local stimulus properties. Child Development 1993;64:1191–1203. [PubMed: 8404264]

Frick JE, Colombo J, Saxon TF. Individual and developmental differences in disengagement of fixation in early infancy. Child Development 1999;70:537–548. [PubMed: 10368908]

Gathercole SE, Pickering SJ. Assessment of working memory in six- and seven-year-old children. Journal of Educational Psychology 2000;92:377–390.

Gathercole SE, Willis CS, Emslie H, Baddeley AD. Phonological memory and vocabulary development during the early school years: A longitudinal study. Developmental Psychology 1992;28:887–898.

Giannopulu I, Cusin F, Escolano S, Dellatolas G. Cognitive associations of bimanual haptic visual recognition in preschoolers Clinical europsychology. (in press).

Haith MM, Hazan C, Goodman GS. Expectation and anticipation of dynamic visual events by 3.5-month-old babies. Child Development 1988;59:467–479. [PubMed: 3359865]

Haith MM, McCarty ME. Stability of visual expectations at 3.0 months of age. Developmental Psychology 1990;26:68–74.

Hale S. A global developmental trend in cognitive processing speed. Child Development 1990;61:653–663. [PubMed: 2364741]

Heimann M, Strid K, Smith L, Tjus T, Ulvund SE, Meltzoff AN. Exploring the relation between memory, gestural communication, and the emergence of language in infancy: A longitudinal study. Infant and Child Development 2006;15:233–249. [PubMed: 16886041]

Hollich GL, Hirsh-Pasek K, Golinkoff RM. Breaking the langauge barrier: An emergentist coalition model for the origins of word learning 2000;65(3Serial No 262)Monographs of the Society for Research in Child Development

Hollingshead, AB. The four-factor index of social status. 1975. Unpublished manuscript, Yale University. Available from A.B. Hollingshead, Department of Sociology, Yale University, New Haven, CT 06520)

Jacobson SW, Jacobson JL, Sokol RJ, Martier SS, Ager JW. Prenatal alcohol exposure and infant information processing ability. Child Development 1993;64:1706–1721. [PubMed: 8112114]

Kail R. Developmental change in speed of processing during childhood and adolescence. Psychological Bulletin 1991;109:490–501. [PubMed: 2062981]

Kuhl PK, Meltzoff AN. The bimodal development of speech in infancy. Science 1982;218:1138–1141. [PubMed: 7146899]

Leonard LB, Weismer SE, Miller Ca, Francis DJ, Tomblin JB, Kail RV. Speed of processing, working memory, and language impairment in children. Journal of Speech, Language, and Hearing Research 2007;50:408–428.

McCune-Nicolich L. Toward symbolic functioning: Structure of early pretend games and potential parallels with language. Child Development 1981;52:785–797.

Miller CA, Kail R, Leonard LB. Speed of processing in children with specific language impairment. Journal of Speech, Language, and Hearing Research 2001;44:416–433.

Mirsky, AF. Disorders of attention: A neuropsychological perspective. In: Lyon, GR.; Krasnegor, NA., editors. Attention, memory, and executive function. Baltimore, MD: Brooks; 1996. p. 71-96.

Mundy PC, Seibert JM, Hogan AE, Fagan JF. Novelty responding and behavioral development in young, developmentally delayed children. Intelligence 1983;7:163–174.

Nelson CA. The ontogeny of human memory: A cognitive neuroscience perspective. Developmental Psychology 1995;31:723–738.

Pan BA, Rowe ML, Spier E, Tamis-Lemonda CS. Measuring productive vocabulary of toddlers in low-income families: concurrent and predictive validity of three sources of data. Journal of Child Language 2004;31:587–608. [PubMed: 15612391]

Patterson ML, Werker JF. Two-month-old infants match phonetic information in lips and voice. Developmental Science 2003;6:191–196.

Piaget, J. The psychology of intelligence. New york: Harcourt, Brace; 1950.

Pinker, S. The language instinct. New York: Penguin; 1994.

Posner MI, Petersen S. The attention system of the human brain. Annual Review of Neuroscience 1990;13:25–42.

Posner, MI.; Raichle, ME. Images of mind. Scientific American Books; 1994.

Reese E, Read S. Predictive validity of the New Zealand MacArthur Communicative Development Inventory: Words and Sentences. Journal of Child Language 2000;27:255–266. [PubMed: 10967887]

Reznick JS, Chawarska K, Betts S. The development of visual expectations in the first year of life. Child Development 2000;71:1191–1204. [PubMed: 11108091]

Rose SA, Feldman JF. Infant visual attention: Stability of individual differences from six to eight months. Developmental Psychology 1987;23:490–498.

Rose SA, Feldman JF. Prediction of IQ and specific cognitive abilities at 11 years from infancy measures. Developmental Psychology 1995;31:685–696.

Rose SA, Feldman JF, Futterweit LR, Jankowski JJ. Continuity in visual recognition memory: Infancy to 11 years. Intelligence 1997;24:381–392.

Rose SA, Feldman JF, Jankowski JJ. Attention and recognition memory in the first year of life: A longitudinal study of preterms and full-terms. Developmental Psychology 2001a;37:135–151. [PubMed: 11206428]

Rose SA, Feldman JF, Jankowski JJ. Visual short-term memory in the first year of life: Capacity and recency effects. Developmental Psychology 2001b;37:539–549. [PubMed: 11444489]

Rose SA, Feldman JF, Jankowski JJ. Processing speed in the 1st year of life: A longitudinal study of preterm and full-term infants. Developmental Psychology 2002;38(6):895–902. [PubMed: 12428702]

Rose SA, Feldman JF, Jankowski JJ. Dimensions of cognition in infancy. Intelligence 2004;32:245–262.

Rose SA, Feldman JF, Jankowski JJ. Recall memory in the first three years of life: A longitudinal study of preterms and full-terms. Developmental Medicine and Child Neurology 2005a;47:653–659. [PubMed: 16174307]

Rose SA, Feldman JF, Jankowski JJ. The structure of infant cognition at 1 year. Intelligence 2005b; 33:231–250.

Rose SA, Feldman JF, Jankowski JJ, Caro DM. A longitudinal study of visual expectation and reaction time in the first year of life. Child Development 2002;73:47–61. [PubMed: 14717243]

Rose SA, Feldman JF, Jankowski JJ, Van Rossem R. Pathways from prematurity and infant abilities to later cognition. Child Development 2005;76:1172–1184. [PubMed: 16274433]

Rose SA, Feldman JF, Jankowski JJ, Van Rossem R. A Cognitive Cascade in Infancy: Pathways from Prematurity to Later Mental Development. Intelligence. 2007

Rose SA, Feldman JF, McCarton CM, Wolfson J. Information processing in seven-month-old infants as a function of risk status. Child Development 1988;59:589–603. [PubMed: 3383669]

Rose SA, Feldman JF, Wallace IF. Individual differences in infants' information processing: Reliaibility, stability, and prediction. Child Development 1988;59:1177–1197. [PubMed: 3168635]

Rose SA, Feldman JF, Wallace IF. Infant information processing in relation to six-year cognitive outcome. Child Development 1992;63:1126–1141. [PubMed: 1446544]

Rose SA, Feldman JF, Wallace IF, Cohen P. Language: A partial link between infant attention and later intelligence. Developmental Psychology 1991;27:798–805.

Rose SA, Futterweit LR, Jankowski JJ. The relation of affect to attention and learning in infancy. Child Development 1999;70:549–559. [PubMed: 10368909]

Rose SA, Gottfried AW, Bridger WH. Cross-modal transfer in infants: Relationship to prematurity and socio-economic background. Developmental Psychology 1978;14:643–652.

Ruff HA. The function of shifting fixations in the visual perception of infants. Child Development 1975;46:657–865.

Ruff HA, Lawson HR. The development of sustained, focused attention in young children during free play. Developmental Psychology 1990;26:85–93.

Saffran JR, Aslin RN, Newport EI. Statistical learning by 8-month-old infants. Science 1996;274:1926–1928. [PubMed: 8943209]

Scottish Low Birthweight Study Group. The Scottish low birthweight study: II. Language attainment, cognitive status, and behavioural problems. Archives of Disease in Childhood 1992;67:682–686. [PubMed: 1626984]

Singer S, Corley R, Guiffrida C, Plomin R. The development and validation of a test battery to measure differentiated cognitive abilities in three-year-old children. Educational and Psychological Measurement 1984;44:703–712.

Tallal P, Stark R, Mellitis D. Relationship between auditory temporal processing and receptive language development: Evidence from studies of developmental language delay. Neuropsychologia 1985;23:527–536. [PubMed: 2412182]

Tamis-LeMonda CS, Bornstein MH. Language, play, and attention at one year. Infant Behavior and Development 1990;13:85–98.

Tamis-LeMonda CS, Damast AM, Bornstein MH. What do mothers know about the developmental nature of play? Infant Behavior and Development 1994;17:341–345.

Tamis-Lemonda CS, Shannon JD, Cabrera NJ, Lamb ME. Fathers and mothers play with their 2- and 3-year olds: Contributions to language and cognitive development. Child Development 2004;75:1806–1820. [PubMed: 15566381]

Thompson LA, Fagan JF, Fulker DW. Longitudinal prediction of specific cognitive abilities from infant novelty preference. Child Development 1991;67:530–538. [PubMed: 1914623]

Tomasello M, Farrar J. Cognitive bases of lexical development: Object permanence and relational words. Journal of Child Language 1984;13:495–505. [PubMed: 3793811]

Ungerer JA, Sigman M. The relation of play and sensorimotor behavior to language in the second year. Child Development 1984;55:1448–1455. [PubMed: 6207995]

Uzgiris, IC.; Hunt, JM. Assessment in Infancy: Ordinal scales of psychological development. Urbana, Chicago: University of illinois Press; 1975.

Visscher KM, Kaplan E, Kahana MJ, Sekuler R. Auditory short-term memory behaves like visual short-term memory. Plos Biology 2007;5:0001–0011.

Vouloumanos A, Werker JF. Listening to langauge at birth: evidence for a bias for speech in neonates. Developmental Science 2007;10:159–164. [PubMed: 17286838]

Wallace MT, Carriere BN, Perrault TJ Jr, Vaughan JW, Stein BE. The development of cortical multisensory integration. The Journal of Neuroscience 2006;26:11844–11849. [PubMed: 17108157]

Wallace MT, Ramachandran R, Stein BE. A revised view of sensory cortical parcellation. Proceedings of the National Academy of Sciences 2006;101:2167–2172.

Wentworth N, Haith MM. Event-specific expectations of 2- and 3-month-old infants. Developmental Psychology 1992;28:842–850.

Table 1

Descriptive Statistics

	Full-terms			Preterms			
	N	***M***	***SD***	**N**	***M***	***SD***	***t***
12 Month Measures							
Information-Processing							
Memory							
Visual Recognition: Rose VPC (% Novelty)	126	58.68	5.24	56	57.06	5.75	$1.87^{\dagger}$
Visual Recognition: Fagan VPC (% Novelty)	128	60.29	5.12	54	58.30	6.79	2.16^{*}
Short-term Capacity (Span length)	126	2.54	.83	56	2.48	.81	.44
Delayed Recognition (% Novelty)	126	54.61	6.26	54	54.52	6.15	.09
Recall – elicited imitation (% Correct)	121	42.17	19.64	55	33.69	17.50	2.75^{**}
Representational Competence							
Cross-modal (% Novelty)	118	48.32	4.27	52	48.40	4.86	.11
Symbolic Play (highest level)	113	7.45	2.49	53	6.32	2.73	2.64^{**}
Anticipations – VExP (%)	113	25.13	14.79	51	26.95	16.25	.71
Object permanence (highest level)	113	4.31	.60	51	4.10	.46	2.24^{*}
Attention							
Mean look duration composite [a]	129	−.14	.59	56	.31	.72	4.45^{**}
Shift rate composite [a]	129	.14	.71	56	−.30	.67	3.95^{**}
Speed							
Encoding speed (trials to criterion)	117	10.00	6.21	55	12.89	9.71	2.36^{*}
Reaction time baseline– VExP (ms)	101	293.59	45.09	43	291.58	34.65	.26
Reaction time post baseline– VExP (ms)	113	294.93	31.43	51	289.06	29.39	1.13
Language – CDI production							
Vocabulary Comprehension	124	25.44	15.18	54	23.61	14.41	.75
Vocabulary Production	124	4.17	5.03	54	3.67	4.93	.62
Gestures Produced	124	7.94	2.12	54	7.17	2.39	2.16^{**}
Mental Development							
Bayley MDI	126	97.56	9.75	56	90.09	10.57	4.65^{***}
36-Month Language							
Peabody Picture Vocabulary Test (PPVT)	95	87.76	14.88	42	82.05	17.39	1.97^{*}
Verbal Fluency	98	3.74	4.26	43	4.26	3.48	.85

Note. VPC = Visual Paired-Comparison Task; VExP = Visual Expectation Paradigm; CDI = MacArthur Communicative Developmental Inventory (short form)

[a] An average of variables standardized to a mean of 0.

[†] $p \leq 0.10$.

[*] $p \leq .05$.

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

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

Table 2

Correlations of 12-Month Infant Information-Processing and Developmental Level with Language at 12 and 36 Months

	12-Month Language CDI – Words/Gestures			36-Month Language	
12-Month Measures	**Comprehension**	**Production**	**Gestures**	**PPVT**	**Fluency**
Memory					
Recognition - Rose	.11	.03	.04	.24**	.18*
Recognition - Fagan	.21**	.05	.20**	.15†	.22*
Short-term Capacity	.01	.04	.15†	−.04	.05
Delayed Recognition	.13†	.12	.21**	.20*	.10
Delayed Recall	.24***	.24***	.21**	.28***	.11
Representational Competence					
Cross-modal	.17*	.23**	.09	.41***	.30***
Symbolic Play	.30***	.12	.30***	.12	.22*
Anticipations	.04	.06	−.02	−.11	−.05
Object permanence	.33***	.24**	.14†	.30***	.22*
Attention					
Mean look duration composite	−.05	.02	−.05	.00	.00
Shift rate composite	.12	.09	.05	.09	.05
Speed					
Encoding speed	−.08	−.01	−.06	.03	−.06
Reaction time Baseline	−.06	.03	−.08	−.08	−.03
Reaction time Post Baseline	−.10	−.03	−.06	−.11	−.07
Developmental Level					
Bayley MDI	.32***	.32***	.33***	.29***	.27**

Note. Partial correlations, controlling for birth status; pairwise, n = 118 −174.

†p ≤ 0.10.

*$p \leq 0.05$.

**$p \leq 0.01$.

***$p \leq 0.001$.

Table 3

Correlations among language measures

	12-Month			36-Month	
	Comprehension	Production	Gestures	PPVT	Fluency
12 Month CDI					
Comprehension	—	$.42^{***}$	$.41^{***}$	$.49^{***}$	$.29^{***}$
Production		—	$.35^{***}$	$.40^{***}$	$.31^{***}$
Gestures			—	$.28^{**}$	$.15^{\dagger}$
36 Month Language					
Comprehension (PPVT)				—	$.44^{***}$
Expression (Verbal Fluency)					—

Note. Partial correlations, controlling for birth status; pairwise, $n = 99 – 170$.

[†] $p \leq 0.10$.

[*] $p \leq 0.05$.

[**] $p \leq 0.01$.

[***] $p \leq 0.001$.

Table 4

Regression Models Predicting **Comprehension** (PPVT) at 36 Months from Birth Status and 12-Month Measures of Information Processing and Language

Set / Measure		Cumulative ΔR^2	Cumulative R^2	Final Equation sr^2	Final Equation β	Final Equation *t*
Model 1: Birth status + Infant information processing						
Control		$.028^{*}$	$.028^{*}$			
	Birth Status			.007	.090	1.16
Infant Information Processing		$.308^{***}$	$.336^{***}$			
	Recognition - Rose			.060	.260	3.39^{**}
	Recognition - Fagan			.001	−.011	−.15
	Delayed Recognition			.005	.071	.95
	Recall			.047	.259	3.02^{**}
	Cross-Modal			.116	.364	4.73^{***}
	Symbolic Play			.006	−.094	−1.11
	Object Permanence			.009	.108	1.33
Model 2: Birth status + Infant Language						
Control		$.028^{*}$	$.028^{*}$			
	Birth Status			.011	.112	1.48
Infant Language		$.262^{***}$	$.290^{***}$			
	Comprehension			.095	.361	4.22^{***}
	Production			.039	.226	2.69^{**}
	Gesture			.001	.026	.30
Model 3: Birth status + Infant Language + Infant Information Processing						
Control		$.028^{*}$	$.028^{*}$			
	Birth Status			.008	.094	4.29
Infant Language		$.262^{***}$	$.290^{***}$			
	Comprehension			.050	.281	3.33^{***}
	Production			.010	.121	1.52
	Gesture			.001	.043	.53
Infant Information Processing		$.147^{***}$	$.436^{***}$			
	Recognition - Rose			.044	.227	3.14^{**}
	Recognition - Fagan			.003	−.059	−.81
	Delayed Recognition			.003	.053	.75
	Recall			.018	.167	2.02^{*}
	Cross-Modal			.070	.292	3.95^{***}
	Symbolic Play			.014	−.145	−1.79
	Object Permanence			.004	.068	.89

[*] $p \le 0.05$.

[**] $p \le 0.01$.

[***] $p \le 0.001$.

Table 5

Regression Models Predicting **Expression** (Verbal Fluency) at 36 Months from Birth Status and 12-Month Measures of Information Processing and Language

	Cumulative		Final Equation		
Set / Measure	**ΔR^2**	**R^2**	**sr^2**	**β**	***t***
Model 1: Birth status + Infant information processing					
Control	.005	.005			
Birth Status			.118	−.142	−1.71
Infant Information Processing	.173***	.178***			
Recognition - Rose			.021	.153	1.84
Recognition - Fagan			.008	.094	1.10
Delayed Recognition			.002	.043	.52
Recall			.001	.004	.04
Cross-Modal			.055	.248	2.98**
Symbolic Play			.019	.162	1.75
Object Permanence			.005	.075	.86
Model 2: Birth status + Infant Language					
Control	.005	.005			
Birth Status			.007	−.083	−1.01
Infant Language	.120***	.125***			
Comprehension			.030	.202	2.16*
Production			.038	.224	2.44*
Gesture			.001	−.030	−.33
Model 3: Birth status + Infant Language + Infant Information Processing					
Control	.005	.005			
Birth Status			.027	−.121	−1.46
Infant Language	.120***	.125***			
Comprehension			.010	.125	1.29
Production			.025	.186	2.04*
Gesture			.003	−.067	−.72
Infant Information Processing	.100*	.225***			
Recognition - Rose			.027	.120	1.46
Recognition - Fagan			.004	.070	.84
Delayed Recognition			.001	.036	.44
Recall			.003	−.063	−.67
Cross-Modal			.036	.205	2.46*
Symbolic Play			.021	.175	1.88
Object Permanence			.001	.042	.49

* $p \le 0.05$.

** $p \le 0.01$.

*** $p \le 0.001$.