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Infants' Early Ability to Segment the Conversational Speech Signal Predicts Later Language Development: A Retrospective Analysis

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Two studies examined relationships between infants' early speech processing performance and later language and cognitive outcomes. Study 1 found that performance on speech segmentation tasks before 12 months of age related to expressive vocabulary at 24 months. However, performance on other tasks was not related to 2-year vocabulary. Study 2 assessed linguistic and cognitive skills at 4–6 years of age for children who had participated in segmentation studies as infants. Children who had been able to segment words from fluent speech scored higher on language measures, but not general IQ, as preschoolers. Results suggest that speech segmentation ability is an important prerequisite for successful language development, and they offer potential for developing measures to detect language impairment at an earlier age.

Keywords: speech segmentation, language development, outcomes, infant, individual differences

Mastery of language is a prodigious feat that most children appear to accomplish quickly and easily. Moreover, children from across a range of linguistic communities appear to reach similar stages in language development at comparable points in time. These facts suggest that infants bring an array of perceptual and cognitive strategies to the task of analyzing their native language. In the past 20 years, there has been a vast increase in the amount of research documenting these auditory and cognitive processing skills (for recent reviews, see Gopnik, Meltzoff, & Kuhl, 2000; Jusczyk, 1997; Werker & Tees, 1999).

Despite the presumed relationship between infant processing abilities and children's later language development, few studies have attempted to link skills shown by particular infants with those individual children's later success at language learning. There are a number of reasons for this gap in the literature. To begin with, longitudinal studies are both time-consuming and expensive to complete. More critically, however, infant performance on processing tasks tends to be quite variable; most infant research studies have included many infants who fail to demonstrate the skills shown by their age-mates, despite the fact that most of these children apparently go on to acquire language skills within the normal range. This variability has been presumed to be the result of random factors, such as attention or crankiness, rather than an indication of developmental risk factors; for these reasons, relatively few studies have explored the long-term outcomes of children showing varying levels of performance on speech processing tasks as infants.

Although an ideal study would follow infants who have participated in speech processing studies longitudinally throughout their childhood to ascertain possible relationships among measures, a reasonable first step is to examine this issue retrospectively. In this article, we report on the results of an investigation linking later language and cognitive outcomes to infants' early performance on speech processing tasks. In the sections below, we briefly review the literature on infants' perceptual abilities, noting particular skills that might be predicted to be important for later language development. We then discuss the extant literature linking infant performance to long-term outcomes. Finally, we present two studies in which we identified infants who had participated in experiments investigating an array of speech processing skills and assessed them at two stages during their preschool years.

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Prior Literature on Infants' Perceptual Abilities

A growing body of research has examined the auditory and cognitive processing skills that might underlie the rapid pace of child language acquisition. Many of these processing abilities appear to be in place very early in life, as has been demonstrated both with infant behavioral responses and electrophysiological measures such as event-related potentials (ERPs; see the recent discussion by Weber, Hahne, Friedrich, & Friederici, 2004).

This research has documented that infants possess a wide array of capacities at a very young age. Infants can discriminate phonetic contrasts categorically by 1 month of age (Eimas, Siqueland, Jusczyk, & Vigorrito, 1971). By the end of the 1st year of life, infants' ability to perceive nonnative contrasts declines as a result of the influence of the ambient native language surrounding them (e.g., Werker & Tees, 1984; but see Best, McRoberts, & Sithole, 1988), and their babbling begins to correspond to the native-language phonology (Boysson-Bardies, Sagart, & Durand, 1989). Their perception of native-language phonemes also begins to change with experience (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992), and infants start to show listening preferences to a wide range of native-language patterns, including both stress and phonotactic patterns within words (Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994).

Many speech processing skills that might logically bootstrap early language acquisition in infants have been explored. One critical skill that infants need to acquire is the ability to recognize and segment individual words from the fluent speech stream. Most speech directed toward infants takes the form of multiword sentences (see, e.g., Aslin, Woodward, LaMendola, & Bever, 1996; Bernstein Ratner & Rooney, 2001; Newman, 2003; van de Weijer, 1998). Thus, to begin mapping meaning onto word forms, infants must be able to subdivide these sentences into their individual words. A number of studies over the past decade have begun exploring infants' abilities in this regard, on the basis of the assumption that this skill would be critical for subsequent language acquisition.

The first such study familiarized infants 7.5 months of age with two target words presented in isolation (Jusczyk & Aslin, 1995). Infants were then tested on their ability to recognize these same words embedded in a fluent speech context. Infants in this study listened longer to passages containing the words with which they had been familiarized than they listened to passages containing unfamiliarized words, demonstrating an ability to detect words in a fluent speech context. Another group of infants were familiarized with fluent speech passages and then tested on their ability to recognize component words; these infants similarly showed an ability to identify (and learn) words spoken in the passages. This original study examined only monosyllabic words beginning with a consonant. More recent work examining longer words (Houston, Santelmann, & Jusczyk, 2004; Jusczyk, Houston, & Newsome, 1999) and words beginning with vowels (Mattys & Jusczyk, 2001) has shown that the ability to segment words continues to develop until at least 16 months of age. Other studies have identified potential cues that infants can use to perform segmentation tasks, particularly cues such as statistical information, phonotactic information, and prosodic information (see, e.g., Brent & Cartwright, 1996; Cairns, Shillcock, Chater, & Levy, 1997; Echols, Crowhurst, & Childers, 1997; Jusczyk, Cutler, et al., 1993; Saffran, Aslin, & Newport, 1996). Moreover, infants appear capable of performing these segmentation tasks even in the presence of competing noise (Barker & Newman, 2004; Hollich, Newman, & Jusczyk, 2005; Newman & Jusczyk, 1996) and talker variability (Houston & Jusczyk, 2000).

However, despite a large literature documenting these infant processing abilities and theorizing about how such skills would be necessary for language acquisition, few studies have directly examined the relationship between the presence or absence of these skills and language acquisition in the same individuals. Most studies have reported on abilities evidenced by the majority of infants tested and only reported group results; there has been little work comparing infants who succeeded in these infant processing tasks with those who did not. This is somewhat surprising, given that variability in performance within and across infant test groups is well documented (Tsao, Liu, & Kuhl, 2004). As a specific example, although the majority of infants succeed at segmentation tasks between 7 and 12 months of age, some infants do not. Jusczyk et al. (1999) reported that whereas 18 of 24 infants listened longer to familiar words with a strong–weak stress pattern in their study, 6 did not. Houston and Jusczyk (2000) reported that only 24 of 36 infants generalized learning across different female talkers and only 18 of 24 generalized across different male talkers. This pattern of mixed performance is virtually universal in infant speech processing research (see Tsao et al., 2004). As we note below, recent work has begun to explore whether a failure to perform a given speech processing task in a laboratory setting has any implications for later language development. If laboratory failures represent a true weakness in ability to segment or analyze the speech stream, this would presumably lead to a delay in children's acquisition of vocabulary. In fact, there is preliminary evidence to suggest that segmentation abilities may be quite delayed in children with identifiable syndromes known to be accompanied by cognitive deficits and depressed language skills (Nazzi, Paterson, & Karmiloff-Smith, 2003), supporting the idea that segmentation may be a necessary precursor to normal patterns of language development.

There also has been little work examining the development of prelinguistic skills longitudinally to ascertain whether variability in infant perceptual ability has any bearing on later language profiles. This is particularly important for at least two reasons. First, although infant speech processing skill is believed to enable infant bootstrapping of the ambient language, our understanding of how perceptual processing skills relate to speech and language development is by necessity speculative. Showing that an infant can perform a given perceptual task in a laboratory setting does not currently enable us to say that the skill assessed by the task is prerequisite to timely or successful acquisition of a given linguistic milestone.

A second reason why it is valuable to explore individual infants' profiles of speech processing ability and later language achievement is that a significant proportion of children do experience difficulty with language acquisition. In the extreme, such difficulty can result in a diagnosis of specific language impairment (SLI). In the United States, it has been estimated that between 12% and 13% of children may be characterized as having SLI at kindergarten entry (Klee, Pearce, & Carson, 2000). The diagnosis of SLI implies a failure to acquire language normally despite having adequate hearing, intelligence, and motor function. Underlying deficits in speech processing have already been targeted as a potential cause of SLI, and differences in speech processing ability could likewise account for variability within the normal range of language function in children. One well-developed account of the basis for SLI places the source of dysfunction in impaired temporal auditory processing of speech input (Tallal, Stark, & Mellits, 1985). Studies supporting this account have shown that children with SLI have difficulty perceiving and/or processing brief and rapidly presented acoustic stimuli (e.g., Tallal & Stark, 1981). Such a difficulty would greatly impair the child's ability to abstract phonological features of the input and link them to the lexical, morphological, and syntactic properties of the target language. Other studies of children with SLI have identified additional weaknesses that they display on a variety of speech perception tasks (Leonard, McGregor, & Allen, 1992; Sussman, 2001; Thibodeau & Sussman, 1979). Thus, we might expect children who eventually display lower levels of language ability to show difficulties in a variety of infant processing tasks. Once identified, some perceptual deficits may be responsive to targeted forms of therapeutic intervention that in turn improve the child's language abilities (Tallal et al., 1996).

Beyond the question of isolating the specific processing deficit(s) that lead to delayed language development or frank SLI, concern has been voiced over the inability to detect markers of clinically relevant language delay or disorder in very young children. Although parental report has enabled improved identification of delayed language development by 24 months (Fenson et al., 1994; Rescorla, 1989), few candidates have emerged as effective predictors of later language outcome prior to this age (Dale, Price, Bishop, & Plomin, 2003). However, there is a small but growing body of evidence that some aspects of infant speech processing relate to children's later language. Thus, describing how differences in infant processing skills might relate to later language development could provide a means for earlier identification of children at risk for language delays.

The possible link between early speech processing and later language acquisition has been commented on by several researchers. Jusczyk (1997) noted, "It would be helpful to begin to explore the possibility of individual differences in the way that speech perception capacities develop . . . . In fact, data about individual infants who are followed longitudinally could provide cues as to why individual differences in speech production are likely to occur" (p. 231). Chiat (2002) suggested that careful examination of speech segmentation and the form-to-meaning mapping process should be the "first place to look for hypotheses about impairments in language acquisition" (p. 114).

Longitudinal Studies Linking Infant Performance to Long-Term Outcomes

To date, there have been a limited number of longitudinal studies linking infant perceptual skills to later language outcomes. One series of investigations has explored relationships between electrophysiological responses to speech in infants and the infants' subsequent language profiles. For example, Molfese and colleagues (see, e.g., Molfese, Molfese, & Espy, 1999) found that ERP responses to both speech (particularly to vowels) and nonspeech stimuli predicted language status through age 5 and reading performance through age 8 (see also, Molfese, 1989). Using discriminant function analysis with ERP data, Molfese and Molfese (1997) were able to correctly classify typically developing and language-disordered children with better than 90% accuracy. These results suggest there may be a link between early speech processing and later development, although they do not provide a hypothetical rationale for why these particular skills should be related.

A second set of studies (see Benasich, Thomas, Choudhury, & Lappänen, 2002) has attempted to strengthen the specific hypothesis that either clinical language impairment or SLI in particular emerge out of a difficulty in processing rapidly presented and brief auditory stimuli, such as the transitional cues that permit identification of stop consonants (Tallal et al., 1985). Benasich and colleagues followed infants genetically at risk for SLI and appraised both behavioral and electrophysiological indices of rapid auditory processing (Benasich & Tallal, 1996; Benasich et al., 2002). They found that infants' thresholds for detecting differences between stimuli at 6–10 months of age were significantly related to their expressive and receptive language outcomes at 36 months; infants who had higher thresholds showed poorer language outcomes. These studies are consistent with an earlier finding (Trehub & Henderson, 1996) that linked skill in gap detection at 6 and 12 months of age with vocabulary size and mean length of utterance between 16 and 29 months.

Most recently, Tsao, Liu, and Kuhl (2004) followed a cohort of 24 infants to see whether their ability to discriminate a non-English vowel contrast at 6 months of age was related to maternal report of vocabulary from 13 to 24 months by using the MacArthur (now MacArthur–Bates) Communicative Development Inventory (MCDI; Fenson et al., 2000, 1994). Twenty infants were followed until age 13 months, at which point a significant correlation was found between laboratory measures and language outcomes. Time to criterion for the laboratory task was most closely correlated with language comprehension, whereas accuracy at the task was most closely associated with the number of words produced by the infants. For 13 infants who the study was able to track to 24 months, time to criterion, but not accuracy at the discrimination task, was highly correlated with expressive lexicon, production of irregular words, and grammatical complexity of the children's utterances. The authors suggested that infant speech processing abilities can predict variability in language outcomes through the 2nd year of life. However, they also noted that individual children's language profiles showed variability from the 1st to 2nd birthday, a problem that persists even through the 3rd and 4th years of life (Rescorla & Lee, 2000). They also cautioned that differences in both laboratory performance and later language profiles could reflect more generalized cognitive mechanisms.

Thus, the available studies suggest a potential relationship between early speech processing skills and later variation in language development. However, some aspects of prior research remain problematic. For example, in all of these studies, infants were tested on very brief stimuli that were, in most cases, nonlinguistic. Extrapolating from performance with nonspeech stimuli to the actual task of language acquisition presents difficulties, some of which have been noted in evaluations of the ability of the rapid auditory processing theory to account for the behavioral features of SLI (see Leonard, 1997; Rosen, 2003, for reviews). Some of the laboratory profiles that have been observed (such as difficulties distinguishing between voiced and voiceless consonants or among vowels) do not seem to match the primary deficits associated with delayed or disordered language in children. Thus, although prior research may have identified a fundamental difference that characterizes slow language development and/or SLI, it is not clear how these processing constraints lead to the typical impairments seen in children with delayed language.

A second difficulty with the prior research is that many studies have followed children only up until the age of 2 years. Yet many children who have low vocabulary scores at 2 years appear to catch up with their peers by 3–4 years of age (Leonard, 1997; Rescorla & Lee, 2000), suggesting the need to track language outcomes until at least that age. Differences in the *pace* of language acquisition over time that can be linked to early perceptual performance may strengthen models describing the roles that given perceptual skills might play in the process of language development. Perceptual skills that predict eventual language *outcomes* have crucial clinical ramifications for identifying and serving children with SLI and other frank disorders of language function. Finally, because children's performance on laboratory tasks and their subsequent language profiles may both be determined by more generalized cognitive abilities, eventual outcomes should include some later measure of nonverbal ability that cannot easily be associated with the skill hypothesized to relate to acquisition of linguistic targets.

Thus, taken together, a rich body of research suggests that, first, typically-developing infants demonstrate a range of speech processing abilities in the first 12 months of life that should have functional ramifications for successful and timely language development. However, virtually none of the prior work has attempted to actually relate differences in individual infants' successes with such tasks to their own later language profiles. Those few studies which have explored this possibility have strongly suggested that, second, prelinguistic speech processing predictors of later language acquisition can be identified in infancy. Moreover, identification of such predictors has the potential to greatly inform theoretical models of successful and delayed language development, as well as to provide possible approaches to remediation of language-learning deficits.

Study 1

The first of two studies reported here was based on retrospective analysis of an archival set of data obtained by the late Peter Jusczyk of Johns Hopkins University. Over 400 infants had participated in a variety of tasks designed to measure speech processing skills such as the ability to recognize familiarized words embedded in fluent speech, to respond to statistical probabilities of words in spoken English, and to associate spoken words with visual referents, among many other study tasks. Many of the resulting published studies are considered groundbreaking in their ability to identify potential skills that preverbal infants bring to the language-learning process (see Jusczyk, 1997, for a full discussion). However, both published reports and discussions with the Johns Hopkins team confirmed that a minority of the infants who met their selection criteria in each of the studies did not demonstrate such abilities, despite apparently adequate attention span and compliant behavior during testing. We examined whether these differences in infant performance correlated with expressive vocabulary outcomes at 2 years of age.

Original Studies

As a first approach, we concentrated on three different types of language studies to see which (if any) were related to later language development. These studies, and their general findings, are listed in Table 1. We grouped the Hopkins infant studies into three general types: studies investigating language discrimination abilities, studies investigating speech stream segmentation abilities, and studies investigating prosodic bootstrapping abilities. Language discrimination studies presented infants with two different languages or dialects. The ability to distinguish between different languages is a critical skill for children in multilingual environments (e.g., Mehler, Dupoux, Nazzi, & Dehaene-Lambertz, 1996) and might also be taken as representative of the more general ability to categorize the speech input into particular classes or types. Infants in these studies were familiarized with passages in one language and then heard new passages in either the same language (or dialect) or a different language (or dialect). If the infants listened longer to the items in the new language, it was taken as evidence of an ability to discriminate the two languages. These studies were performed when the infants were 5 months of age, and results suggest that the majority of tested infants could discriminate between languages that differed in rhythmic class (English–Japanese, Italian–Japanese) and could discriminate between two languages in the same rhythmic class if they were already familiar with one of the languages (English–Dutch, British English–American English; Nazzi, Jusczyk, & Johnson, 2000).

As mentioned earlier, the ability to segment is necessary to analyze fluent speech into its component parts. In speech-stream-segmentation studies, infants were familiarized with words such as *cup*, and they then heard fluent speech passages that either did or did not include this word. Infants' overall attention to these two types of stories was compared. If infants listened longer to one type of story than to the other type of story, it was taken as an indication that infants were able to segment the fluent speech stream into its individual words and to recognize the correspondence between words in isolation and words in fluent speech (see Jusczyk & Aslin, 1995, for the original use of this paradigm). Particular experiments that used this task examined properties of the signal that might influence performance, such as the length of the words, whether the words contained typical or atypical stress patterns for the language, phonotactic properties of the words, and whether the familiarization and test passages were spoken by the same talker or by different talkers (Houston & Jusczyk, 2000; Houston, Jusczyk, Kuipers, Coolen, & Cutler, 2000; Houston et al., 2004; Johnson & Jusczyk, 2001; Johnson, Jusczyk, Cutler, & Norris, 2003; Mattys & Jusczyk, 2001). These studies were performed when the infants were from 7.5 to 12 months of age. Results from these studies are summarized in Table 1.

Finally, prosodic bootstrapping studies were designed to explore infant sensitivity to prosodic markers of syntactic structure. This skill may be an early marker of the ability to pick up syntactic properties in the input. Infants were first familiarized with a short sequence of words, such as *rabbits eat leafy vegetables*. After the familiarization phase, infants heard two different types of passages: passages containing that sequence of words within a single syntactic unit (e.g., "Many animals prefer some things. *Rabbits eat leafy vegetables.* Taste so good is rarely encountered") and passages in which the same words crossed over a syntactic boundary (e.g., "John doesn't know what *rabbits eat. Leafy vegetables* taste so good"). In the latter sequence, prosodic cues to sentence boundaries would suggest that the words *rabbits eat* should not be grouped with *leafy vegetables*. At both 6 and 9 months, infants demonstrated a preference for passages that preserved prosodic

Table 1
Summary of Laboratory Studies in Which the Infants Participated

Knowledge area	Age	Major finding	Citation
Language discrimination	5.0 months	Infants can discriminate languages from different rhythmic classes, for example, British English vs. Japanese; they can also distinguish native from nonnative dialects, such as British vs. American English.	Nazzi, Jusczyk, & Johnson, 2000
Prosodic preference			
	6.0 months	Infants prefer sequences of words taken from well-formed prosodic units (e.g., clauses or phrases) over identical words that form a prosodically ill-formed sequence. Infants use prosody to parse continuous speech.	Nazzi, Kemler Nelson, et al. 2000; Soderstrom et al., 2003
	9.0 months	Infants prefer sequences of words taken from within a phrase (e.g., noun phrase NP) over identical sequences that cross the noun phrase/verb phrase boundary. Infants are sensitive to prosodic features that signal phrase boundaries.	Soderstrom et al., 2003
Speech segmentation			
	7.5 months	Infants familiarized with isolated words attend longer to fluent speech that contains these words if speaker gender is held constant; they can segment words from fluent speech across talkers within a gender. They can also segment trisyllabic words from fluent speech, but they use stress as a cue to do so.	Houston & Jusczyk, 2000; Houston et al., 2004
	8.0 months	Infants show a trochaic bias in word segmentation; they segment the bisyllables at beginning of 3-syllable nonsense words better than those at the end. They also do not false alarm to items that cross a word boundary (such as *dice* in *cold ice*).	Johnson & Jusczyk, 2001; Mattys & Jusczyk, 2001
	9.0 months	Infants can segment familiarized words from fluent speech in a foreign language that is rhythmically similar to their native language, and infants familiarized with passages of fluent speech that contain good phonotactic cues can recognize words segmented from them.	Houston et al., 2000; Mattys & Jusczyk, 2001
	10.5 months	Infants familiarized with isolated words attend longer to fluent speech that contains these words even if speaker gender varies.	Houston & Jusczyk, 2000
	12.0 months	Infants only segment words from bisyllables when the remaining portion is a possible word; they avoid stranding impossible sequences.	Johnson et al., 2000

characteristics of the familiarization stimuli (Nazzi, Kemler Nelson, Jusczyk, & Jusczyk, 2000; Soderstrom, Seidl, Kemler Nelson, & Jusczyk, 2003).

Taken as a group, the children participated in nine published studies (see Table 1) that reported significant evidence of infants' abilities to perform a wide array of speech processing tasks (Houston & Jusczyk, 2000; Houston et al., 2000, 2004; Johnson & Jusczyk, 2001; Johnson et al., 2003; Mattys & Jusczyk, 2001; Nazzi, Jusczyk, & Johnson, 2000; Nazzi, Kemler Nelson, et al., 2000; Soderstrom et al., 2003). We examined only studies in which a clear, statistically significant pattern of typical performance was reported. Yet in each of these studies, there were some infants who did not follow the group trend. A retrospective analysis was designed to contrast those children who did show the typical listening pattern versus those who did not.

We predicted that those infants with poor vocabulary skills at 2 years of age would have been less likely to have succeeded at speech processing tasks as infants. In particular, we expected to find a relationship between later vocabulary outcomes and early *segmentation* skills. We did not expect that infant *language discrimination* skills would relate to later language outcomes, as there is no theoretical reason to expect a relationship between language discrimination and vocabulary learning, at least not for children raised in a monolingual environment. Although prosodic bootstrapping skills are theoretically related to later syntactic development rather than lexical development, prior work has shown strong relationships between children's MCDI scores at 2 years and their later syntactic development. Moreover, phrasal boundary cues have been shown to aid adults learning artificial languages (Morgan, Meier, & Newport, 1987). We therefore expected that we might find a weak relationship between this infant skill and later outcomes as well.

Method

Participants

The parents of 412 original participants of the infant laboratory studies described above completed a parental questionnaire regarding their children's language development when they reenrolled children for a series of experiments at 24 months of age. All studies carried out in the Johns Hopkins University laboratory conventionally excluded children raised in non-native English-speaking or bilingual households, children with known developmental syndromes, children with a history of ear infections and potential hearing loss at time of testing, and children born more than 8 weeks preterm. Information on race and/or ethnicity, education, and family socioeconomic status was not available.

Procedures and Materials: 24-Month Outcomes

At 24 months, all of the children's parents completed the MCDI, a parental checklist measure of a child's expressive vocabulary. To maximize potential associations between prelinguistic and later skills, we inspected the data to identify the top and bottom 15% of the sample

Table 2
Summary of Participants in Study 1

Infant laboratory task	High-MCDI group *n*	Low-MCDI group *n*	Success in high-MCDI group *n*	Success in low-MCDI group *n*	Success in high-MCDI group %	Success in low-MCDI group %
Language discrimination	13	9	11	6	84.6	66.7
Prosodic bootstrapping						
6 months	10	6	7	3	70.0	50.0
9 months	5	11	4	5	80.0	45.5
Total	15	17	11	8	73.3	47.1
Multisyllabic segmentation & segmentation across talkers	24	23	16	7	66.7	30.4
Phonotactic cues in segmentation						
9 months	11	7	9	3	81.8	42.9
12 months	8	13	7	6	87.5	46.2
Total	19	20	16	9	84.2	45.0
Segmentation across genders	17	17	10	7	58.8	41.2

Note. MCDI = MacArthur–Bates Communicative Development Inventory.

for reported vocabulary size.[1] The range of scores for these high-performing and low-performing children was virtually indistinguishable from the range found when the vocabulary checklist was originally normed (Bates, Dale, & Thal, 1995), suggesting that the infant study population contained extremely disparate cohorts of language learners, despite screening and exclusionary procedures meant to enroll only "typically developing infants." Those in the high-MCDI group had an average vocabulary of 646 words ($SD = 55.1$; range: 566–777); those in the low-MCDI group had an average vocabulary size of 73 words ($SD = 34.4$; range: 2–142). Moreover, it is important to note that the majority of infants whose language development profiles ranked them in the bottom decile at 2 years of age had reported vocabulary sizes that qualified them for a diagnosis of specific emergent language delay (Rescorla, 1989), a precursor of SLI. The sample of children was then further narrowed to 119 children (data from the remaining 5 could not be cross-referenced).

Next, the records from these 119 children were linked to archived laboratory performance on the array of tasks described earlier. The archival data consisted of dichotomous classification of each child's laboratory performance as successful or unsuccessful, as detailed in the next section. We asked whether children in the two groups (high vocabulary vs. low vocabulary) followed group performance profiles for the experimental tasks. Each original study excluded from analysis any child whose behavior was affected by fussiness, sleepiness, or other signs of behavioral unreliability. Thus, only data from children who attended to study tasks were analyzed. Table 2 provides details of participants' laboratory experiences and MCDI scores.

For each study in question, we analyzed laboratory performance of children whose MCDI 2-year profiles were high (>85%) or low (<15%). The number of children who "succeeded" (conformed to the group trend demonstrating the infant perceptual ability) and "failed" (did not orient to the stimuli as did the majority of their study peers) was tabulated. If the infant looked longer (on average) in the correct direction, it was considered a successful outcome, regardless of the degree of this looking-time difference; that is, any trend (regardless of how small) of longer looking times to the correct stimuli was considered successful. Any infants who showed longer looking times to the incorrect stimuli were considered to have failed the task. Because of the very small and uneven cell frequencies, Fisher's exact tests were computed for this set of exploratory analyses.

Results

Language Discrimination

A total of 22 children participated in this study, which involved infants 5 months of age. In the high-MCDI group, 85% of the children had been successful as infants, whereas 67% of the children in the low-MCDI group had been successful as infants. Thus, for both groups, the majority had been successful, and the two groups do not differ statistically ($p = .609$), perhaps because of small sample size. This suggests that infants with higher vocabularies at 2 years of age had not necessarily been any more adept at distinguishing between different languages at 5 months of age.

Speech Segmentation

Speech segmentation studies were performed at several different ages, ranging from 7.5 months to 12 months. Because all of these studies tested the same general concept (the ability to separate words from fluent speech), we first examined the data by combining across these different studies. Seventy-seven infants participated in one or more of these studies. We then explored studies testing different aspects of segmentation separately.

Combining across the segmentation studies at different ages, there was a 71% success rate for infants from the high-MCDI group and a 38% success rate for children in the low-MCDI group. This difference is significant at $p < .0005$, suggesting that seg-

[1] A major factor influencing the decision to truncate the data to the extreme 30% of the sample was the death of author Peter W. Jusczyk early in the process of Study 1 and the imminent closure of the Johns Hopkins University laboratory, which would limit access to laboratory records. It was thought that targeting extreme profiles of performance was most likely to identify potential relationships among the variables of interest before the data became permanently inaccessible.

mentation ability in general may be related to later vocabulary. We then proceeded to examine the segmentation studies individually.

Multisyllabic segmentation and segmentation across talkers. Studies involving infants 7.5 and 8.0 months of age investigated infants' ability to segment multisyllabic words and their ability to generalize segmentation abilities across talkers. Forty-seven children participated in two separate versions of this task. In the high-MCDI group, 67% of the children had been successful as infants, whereas 30% of the children in the low-MCDI group had been successful as infants, a significant difference ($p < .05$).

Sensitivity to phonotactic cues in segmentation. Studies involving phonotactic constraints in segmentation were performed at two different ages, 9 months and 12 months. Combined, there was an 84% success rate for infants from the high-MCDI group and a 45% success rate for children in the low-MCDI group. This difference is significant ($p < .05$).

Looking at these separately, 18 infants participated in studies investigating infants' sensitivity to phonotactic cues at 9 months of age. In the high-MCDI group, 82% of the children had been successful as infants, whereas 43% of the children in the low-MCDI group had been successful as infants. This difference did not reach statistical significance ($p = .14$), although there was a trend in the appropriate direction.

At 12 months of age, the infants were given a task that tested whether they avoided segmenting words in ways that would "strand" illegal phonotactic sequences (sequences that could not constitute a word). Twenty-one infants participated in this task. In the high-MCDI group, 88% had segmented the words appropriately. In the low-MCDI group, 46% of the infants performed similarly. This difference does not reach statistical significance ($p = .085$), although there is again a trend in the appropriate direction. Because the combination of the 9- and 12-month-old infant studies did reach significance, lack of power may be a factor in why neither version reached significance individually.

Speech segmentation across speaker gender. At 10.5 months, infants appear to be able to generalize segmentation ability across genders. Thirty-four infants participated in the study examining this issue. In the high-MCDI group, 59% of the children had been successful as infants, whereas 41% of the children in the low-MCDI group had been successful as infants. This difference did not approach significance ($p = .49$).

In summary, children who had large expressive lexicons at 2 years of age generally had performed better on segmentation tasks in the second half of their 1st year of life. This difference was clearest for infants who had participated in segmentation tasks at 7.5 and 8.0 months of age, although this may in part be the result of the smaller number of participants in the studies involving slightly older infants. The ability to generalize segmentation across male and female speakers seemed least likely to be related to later vocabulary acquisition.

Prosody (6- and 9-Month Prosodic Preference)

Studies of prosodic preferences were performed at two different ages, 6 months and 9 months. A total of 30 infants participated in the two studies (16 at 6 months and 16 at 9 months, with 2 participating at both). Combining across these two variants, there was a 73% success rate for infants from the high-MCDI group and a 47% success rate for children in the low-MCDI group. Despite this apparent difference, the distribution is not significant by Fisher's exact test ($p = .17$). This null finding may be the result of a lack of statistical power; it therefore remains unclear whether the ability to detect prosodic cues to syntax relates to later vocabulary development. It is also possible that MCDI scores do not optimally capture potential linguistic advantages conveyed by successful performance on prosodic preference tasks as an infant.

Summary of Findings From Study 1

Looking across all the ages and tasks, we found that children who had large expressive lexicons at 2 years of age tended to have demonstrated better perceptual performance on language tasks in their 1st year of life than did their low-MCDI study mates (overall, 76% of the high-scoring MCDI children had been successful as infants, whereas 41% of the low-scoring children had been successful; $p < .0001$). This pattern was strongest for infant segmentation skills. Thus, consistent with recent findings by Tsao et al. (2004), who used a different infant speech processing task but similar outcome measures, this preliminary study found evidence that certain perceptual processing skills in infancy are associated with differences in early expressive language development. The most robust differences between children who had high versus low expressive vocabulary scores at 24 months were found for speech segmentation studies. Segmentation tasks measure a child's ability to separate words from fluent speech and store them for later recall. This is a necessary step in learning word forms that can be attached to function and meaning in the language. We had predicted that poor segmentation ability would lead to slower vocabulary growth and that we would therefore find a strong relationship between these measures. Although some proportion of infant-addressed vocabulary appears in isolation (e.g., citation naming; Aslin et al., 1996; Bernstein Ratner & Rooney, 2001; Newman, 2003), and could potentially aid in vocabulary development (Brent & Siskind, 2001), statistical reliance on such input is unlikely to suffice for language learning (Mintz, 2003; but see Brent & Siskind, 2001). A child who could not segment fluent speech (and thus had to depend entirely on such citation naming for word learning) would be at a severe disadvantage, and our results confirm this.

We had not expected to find a relationship between language discrimination and later vocabulary outcomes, and our results were consistent with this expectation. For children raised in a monolingual environment, sensitivity to differences between languages may not be a critical skill. However, the lack of statistical findings for both this skill and the prosodic preference studies also may be the result of a lack of statistical power. This seems especially likely for the prosodic studies, as the percentage of infants in the high-MCDI group who had succeeded in this task was substantially higher than the percentage of infants in the low-MCDI group. Future work will be needed to explore these relationships further.

Study 2

The findings of Study 1 suggested that early speech processing skills, particularly segmentation skills, are related to children's vocabulary at 24 months. Yet, as noted earlier, many children who have low vocabulary scores at 2 years of age appear to catch up with their peers by 3–4 years (Leonard, 1997; Rescorla & Lee, 2000). Thus, we considered it important to augment these results with later follow-up of the children we selected for preliminary analysis to determine whether this pattern continues to hold for older children (i.e., whether the differences in language outcome are stable). In addition, it is possible that the early findings could have been related to general cognitive differences between the two groups of children rather than to language-specific differences. Perhaps children with higher IQ scores would demonstrate both superior processing skills as infants and higher vocabulary scores at 24 months. Thus, to validate any observed associations between language ability and laboratory performance, we considered it necessary to follow the 24-month analysis with a more complete analysis of later language and cognitive development. We focused specifically on infant segmentation skills, as this was the task from Study 1 that showed the strongest relationships with later language outcomes.

Method

Participants

A subset of infants who had participated in Study 1, specifically, those who had participated in speech segmentation studies, were recruited for Study 2. (Too few children had participated in the other types of studies to merit attempts to track outcomes of infant prosodic processing and language discrimination abilities.) Letters were mailed from Johns Hopkins University to families of all of these target children inviting them to participate in full language assessment of their children. Of the 77 families to whom letters were sent, 27 children returned for testing, a return rate of 35%. The children were between 4 and 6 years of age at the time of testing ($M = 55.5$ months, range: 48.5–69.0 months) and included 12 boys and 15 girls. Of these children, roughly half (14) had scored in the upper 15% on the MCDI at 24 months, and 13 had scored in the lowest 15%. Thus, there did not seem to be a bias for parents to refer slower language learners at a higher rate for follow-up assessment.

Of these 27 participants, 26 were Caucasian; parents of the other child opted not to provide this information. The mothers of all infants had at least a college degree; 48% also had a graduate degree. Of the fathers, 82% had at least a college degree, and 37% had a graduate degree as well.

Procedures and Materials

All children were individually tested by a certified speech-language pathologist blinded to their earlier laboratory profiles. All children passed an audiometric pure tone screening at 1,000–4,000 Hz at 20dB bilaterally on the day of testing. The assessment battery included the following measures: the Test of Language Development–Primary (3rd ed.; TOLD-P:3; Newcomer & Hammill, 1997) and the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990). The TOLD-P:3 was selected because it provides separate scales for lexical and syntactic skills. It is one of the most widely used measures of preschool children's language abilities and provides a comprehensive profile of the structural aspects of a child's linguistic skills (McCauley, 2001). It additionally offers a supplemental articulation screening. Potentially, children who did less well in speech processing tasks as infants might have more difficulty mastering correct phonetic representations, which in turn could lead to depressed articulation ability. Alternatively, those toddlers who had lower MCDI scores might have been penalized for less intelligible attempts at early words. In contrast, if speech processing abilities are specifically related to language development, we would not expect to see later relationships with articulation ability.

The K-BIT provides measures of both verbal and nonverbal reasoning and is one of the few norm-referenced cognitive assessment tools appropriate to the age range of the children in the study. To provide some indication of the children's functional performance in a variety of linguistic domains, parents were also asked to complete a behavioral checklist: the Speech and Language Assessment Scale (SLAS; Hadley & Rice, 1993). This criterion-referenced assessment asks parents to compare their child with "other children my child's age," on a 7-point scale, on a variety of queries addressing receptive and expressive grammar, vocabulary, articulation, and pragmatic skills. For example, responses to the item "My child's ability to make 'grown-up sentences' is" could range from 1 (*very low*), to 4 (*normal for age*), to 7 (*very high*).

We were particularly interested in the relationship between early segmentation ability and later language outcome. We therefore classified children as "segmenters" or "nonsegmenters" according to whether or not they succeeded on the infant segmentation studies. Of the 27 children who participated, 16 took part in two ($n = 10$) or more ($n = 6$) segmentation studies as infants; these children were classified as segmenters only if they succeeded in all of the segmentation tasks in which they participated.[2] Of the 27 children, 10 (5 boys, 5 girls) showed successful performance and were labeled segmenters, whereas 17 (7 boys, 10 girls) did not show successful performance and were labeled nonsegmenters. These two groups of participants did not differ in age, $t(25) = 0.15$, $p = .88$, with average ages of 55.3 months for segmenters and 55.7 months for nonsegmenters, or in maternal education levels, $t(25) = 1.24$, $p = .23$, with an average of 17.4 years of education for mothers of segmenters and 16.8 years for mothers of nonsegmenters.

Children classified as segmenters and nonsegmenters were compared on later measures of linguistic and nonverbal performance. We examined the two groups' performances on four sets of measures: language, articulation, general cognitive abilities, and parental report of communicative competence.

Results

The present design results in two groups of children, segmenters and nonsegmenters, who were assessed on four indices: performance on both the Overall Language Quotient and the Supplemental Articulation test on the TOLD-P:3, parental rating of communicative skills on the SLAS, and generalized cognitive function as measured by the K-BIT. Because this retrospective analysis was exploratory in nature, we performed four separate t tests looking for group differences on these four measures. Eta-squared values are reported as magnitude of effect indicators and represent the proportion of variance in the dependent variable explained or accounted for by the differences in the means for the effect hypothesis tested. The eta-squared values range from .00 to 1.00. Values around .01 indicate a small effect, values near .06 indicate a medium effect, and values in the .14 or above range indicate a large effect (Cohen, 1988). We predicted that we would find effects of segmentation on both of the language measures (Overall Language Quotient and SLAS), but not on the articulation or cognitive tests.

Because there were fewer children available for this later language testing than were seen at 24 months, we first repeated the analyses from Study 1 to ensure that the subsample of children returning for follow-up testing appeared representative of the larger sample. We thus separated the 27 children into a high-MCDI group ($M = 622$) and a low-MCDI group ($M = 76$), as before. In the high-MCDI group, 11 children had demonstrated successful speech segmentation abilities, whereas 3 had not; in the low-MCDI

[2] An alternative means of classification for these children would be to identify them as "segmenters" if they succeeded on a majority of segmentation tasks (i.e., 50%). Use of this classification rule leads to the same pattern of results, although the resulting split is more even (13 segmenters, 14 nonsegmenters), allowing for slightly more statistical power.

group, 2 children had shown evidence of ability to segment fluent speech, whereas 11 had not. This distribution is significant by Fisher's exact test at $p = .005$. These results suggest that the older children tested in this study were representative of the full sample tested in Study 1.

The first outcome measure was the overall language quotient on the TOLD-P:3. We note that no children achieved scores on the TOLD-P:3 that would indicate any clinically significant concerns: All would be considered to have performed within or above the normal range by use of conventional criteria for determining language disorder (McCauley, 2001). However, the overall language profiles of children showing early speech segmentation ability were statistically higher than those of children who did not demonstrate such ability, $t(25) = 2.44$, $p < .05$, $\eta^2 = .192$, indicating a large effect, with a mean quotient of 125 for segmenters (range: 108–146) and 111 for nonsegmenters (range: 79–136).

We then examined the parental report of children's communicative abilities using the SLAS. Results on this measure were consistent with the standardized test score findings for the TOLD-P:3. The two groups again differed significantly in their average scores, with segmenters (with an average rating of 6.1 on a 7.0-point scale; range: 4.7–7.0) being rated by their parents as more advanced in their language skills than nonsegmenters (who had an average rating of 5.2; range: 3.2–6.8), $t(25) = 2.35$, $p < .05$, $\eta^2 = .181$, indicating a large effect. (In addition to confirming the standardized test scores that placed all children within the normally functioning range, we note that, as in Lake Wobegon, all but 1 child—a male nonsegmenter—were considered to be above average in language performance by their parents.)

The articulation measure consisted of the supplemental Word Articulation subscale on the TOLD-P:3. Here, there was no significant difference between the two groups, with segmenters scoring at 47% (range: 0%–91%) and nonsegmenters at 44% (range: 1%–91%), $t(25) = 0.17$, $p = .87$, $\eta^2 = .001$. We note that this measure did identify 8 children (4 in each group) who met conventional cutoffs used to define clinical speech impairments, even though articulation ability did not appear to relate to earlier laboratory performance.

Finally, as noted earlier, one possibility is that both the laboratory performance and linguistic differences seen between groups reflected differences in generalized intellectual ability or in attention or distractibility. Perhaps infants with higher IQ scores or infants who are less distractible perform better on segmentation tasks, as well as on tasks of language development. K-BIT profiles do not suggest that this is the case. For the overall K-BIT IQ Composite, segmenters had an average standard score of 120 (range: 98–139), whereas nonsegmenters had an average score of 115 (range: 95–132), $t(25) = 1.08$, $p = .289$, $\eta^2 = .045$. Only 4 children performed at 50% or below (i.e., at a standard score of 100 or less), 2 from each group. No child scored beyond half a standard deviation below the mean.

The K-BIT includes both a verbal and a nonverbal component. Thus, an overall measure could mask an effect located in only one of the two subscales. To ensure that there truly was no difference in generalized cognition between the two groups, we looked at the two portions separately. For the verbal portion of the test, K-BIT Expressive, segmenters had a mean standard of 125 (range: 98–154) and nonsegmenters had a mean score of 115 (range: 93–130), a nonsignificant difference, $t(25) = 1.81$, $p = .08$, $\eta^2 = .12$. For the nonverbal portion of the test, K-BIT Matrices, segmenters had a mean score of 111 (range: 98–128) and nonsegmenters had a mean score of 112 (range: 96–128), also a nonsignificant difference, in addition to being in the opposite direction from that we might have predicted; $t(25) = -0.38$, $p = .71$, $\eta^2 = .006$. Thus, there is no evidence to suggest that the groups differed in general measures of intellectual aptitude or test-taking ability. Although segmentation skills might relate to later language outcomes (as shown on the TOLD-P:3), they do not appear to correlate with generalized intelligence, at least as measured by the K-BIT. Although it is possible that there are subtle nonverbal differences not captured by this test, this test is generally quite robust as a measure of cognitive skills.

These results suggest that the ability to segment words in infancy is related to later language outcomes but not to generalized cognitive ability. However, both of the two language measures examined above tap into a wide range of language abilities; finding an effect of segmentation on these tests does not tell us what aspects of language might be most closely related to infant segmentation performance. One way to investigate this issue is to examine the different subscales within the TOLD-P:3 separately. In particular, this test includes both a Semantics Composite subscale and a Syntax Composite subscale. The Semantics (or vocabulary) Composite includes the three TOLD-P:3 subtests targeting oral and receptive vocabulary skill. There were significant differences between the groups of children on this measure, with segmenters having a mean quotient of 120 (range: 106–139), as compared with 108 (range: 79–132) for nonsegmenters, $t(25) = 2.21$, $p < .05$, $\eta^2 = .163$, indicating a large effect. The Syntax (or grammatical) Composite scores were also markedly different for the two groups of children, $t(25) = 2.26$, $p < .05$, $\eta^2 = .170$, indicating a large effect, with average values of 126 for segmenters (range: 109–147) and 112 for nonsegmenters (range: 72–143). Thus, it appears that segmentation may be related to both of these aspects of language development, rather than to one alone.

To the extent that these language outcomes are related to early segmentation ability, one should be able to predict, on the basis of the outcome measures, whether a child had been able to segment fluent speech as an infant. A discriminant function analysis, with the predictor variables of scores on TOLD-P:3 Semantics Composite, TOLD-P:3 Syntax Composite, SLAS, K-BIT Expressive, K-BIT Matrices, and TOLD-P:3 Word Articulation score, showed that the first three predictors were all significantly related to early segmentation ability. Moreover, the function including these measures correctly predicted segmentation ability for 22 of the 27 children.

Finally, relationships among the outcome variables and early MCDI scores are displayed in Table 3. It should be noted that the highest correlation is observed between the two parent report forms; however, all of the language measures were highly intercorrelated. The nonlanguage measures (articulation and nonverbal intelligence) do not appear to strongly correlate with linguistic skills. Performance on the MCDI at age 2 appears to predict both standardized language assessment scores as well as parental report of communicative proficiency in preschool. Thus, it appears that those children who had advanced vocabularies at age 2 remained relatively advanced in their language skills throughout their childhoods. It does not appear that segmentation provides separate advantages to vocabulary and syntactic abilities, but rather that there may be a degree of continuity in language ability from 7 months of age through the preschool years.

Table 3
Correlations Among Different Language Outcome Measures

Scale	1	2	3	4	5	6	7
1. MCDI	—	.535*	.681*	.450	.624*	.385	.758*
2. TOLD-P:3 Semantics		—	.736*	.076	.600*	.429	.335
3. TOLD-P:3 Syntax			—	.217	.542*	.297	.538
4. TOLD-P:3 Articulation				—	.140	.384	.264
5. K-Bit Expressive					—	.400	.461
6. K-BIT Matrices						—	.228
7. SLAS							—

Note. Pearson's coefficients are reported for all correlations with the exception of those involving the SLAS, for which Spearman rho is used (as the data are not interval). Given the large number of correlations, we set criterion for significance at $p < .005$. MCDI = MacArthur–Bates Communicative Development Inventory; TOLD-P:3 = Test of Language Development–Primary (3rd ed.); SLAS = Speech and Language Assessment Scale; K-BIT = Kaufman Brief Intelligence Test.
* $p < .005$.

General Discussion

The results of these studies suggest that later language profiles in preschool children are related to speech segmentation ability between 7 and 12 months. Thus, these studies add to a recently emerging literature that has linked other aspects of infant speech processing with later language profiles (Benasich & Tallal, 2002; Liu, Kuhl, & Tsao, 2003; Molfese, 1989, 1992; Molfese & Molfese, 1985, 1997; Molfese et al., 1999; Molfese & Searock, 1986; Trehub & Henderson, 1996) as well as strengthen predictions that have been made about the role of certain speech processing skills in bootstrapping successful language development (Aslin et al., 1996; Cairns et al., 1997; Jusczyk, 1997; Werker & Tees, 1999).

In the first study, children who had high vocabulary scores at 24 months (in the top 15% of a large laboratory sample) were shown to be more likely to have succeeded in segmentation tasks as infants than were children who had low vocabulary scores. Other laboratory tasks, such as discriminating between languages or recognizing prosodic cues to syntactic structure, did not seem to show as strong a relationship with later vocabulary accumulation. Although promising, these first results needed to be validated by follow-up of the study children at later ages and by ensuring that infant and toddler performance were not both governed by generalized cognitive ability.

In the second study, therefore, we located a cohort of infants who had participated in segmentation tasks and assessed their language and cognitive skills at between 4 and 6 years of age. Preschoolers who had succeeded at segmentation tasks as infants demonstrated significantly better language skills than did children who had not demonstrated segmentation ability. This advantage extended to both syntactic and semantic abilities, as appraised by a widely used clinical language battery. The two groups did not differ in generalized intelligence. Indeed, nonverbal intelligence scores for the two groups were nearly identical. This is not to say that individuals with significant cognitive deficits might not also show poor segmentation as infants; individuals with Williams Syndrome have been shown to be delayed in their ability to segment fluent speech (Nazzi et al., 2003). Rather, effects of generalized cognition may be a factor only for children who fall outside the range of normal development. Although there was substantial variability in cognitive skills among our participants (with percentile rankings ranging from 37% to 99.5%), all fell within normal limits; within this range, cognitive ability does not appear to be related to infant segmentation skill. This suggests that in our sample, the relationship between segmentation ability and language profiles was not mediated in any apparent way by generalized cognitive function. Rather, it appears to be a specifically linguistic relationship.

The results of both studies suggest that later language development may be related at least in part to one particular skill in infancy, the skill required to identify single words embedded in fluent, running conversational speech. Segmentation tasks measure a child's ability to separate words from fluent speech and store them for later recall. This is a necessary step in learning word forms that can be attached to function and meaning in the language. The relationship between early speech segmentation ability and later language development thus does not appear arbitrary and should logically yield the results we obtained. For example, early vocabulary development theoretically should be greatly facilitated by the ability to locate word boundaries in the input signal of fluent concatenated speech. Children lacking an ability to isolate words from fluent speech would be limited to learning vocabulary from the subset of the instances in which words were presented in isolation, delaying their lexical development. Later vocabulary and grammatical development should be similarly facilitated by an improved ability to segment, particularly if such an ability foreshadows the skill to detect and use small, unstressed function words and bound inflections that form the basis of early grammatical development in children. For these reasons, we had predicted that poor segmentation would lead to slower vocabulary growth and, thus, that we would find a strong relationship between these measures. All of the children in the second study could be considered successful language learners; they demonstrated performance within or above the normal range. However, the relatively depressed scores of the nonsegmenters can be taken as evidence of a subtle delay in the achievement of certain lexical and grammatical skills measured by the tests we used. As norms for the assessments we used are age-referenced, lower scores reflect more immature performance. That is, nonsegmenters were delayed in mastering the meanings of individual words and sentence structures (as measured by performance on age-normed assessment devices). These are skills that logically depend on quick and accurate segmentation of the input into its analyzable components. Future prospective studies that target infants at strong risk to develop clinical language impairment (e.g., because of family history of SLI) might allow us to refine the hypothetical role of segmentation skills in language acquisition. Moreover, the fact that even the nonsegmenters had normal language outcomes suggests that an inability to segment the speech stream at 7–12 months is perhaps best thought of as a delay in acquiring the ability to do so rather than as an overall lack of ability. Determining *when* infants acquire a particular ability (by testing them on the same task across time) rather than simply whether they meet any particular landmark would allow for a more nuanced role of how segmentation plays into later development.

Despite the logical relationship between early segmentation abilities and later language development, the actual finding of such a relationship is in some ways quite surprising. As noted earlier, infant laboratory performance tends to be extremely variable, and performance by any particular infant can be influenced by a variety of outside factors, such as sleepiness, hunger, teething, and so forth. For this reason, only group performance patterns have been thought to be reliable measures; performance by any particular infant in these laboratory tasks has generally been viewed as subject to too many outside variables to be interpretable. Yet here we find that individual infants' performances on a task during infancy predict their language acquisition 4 or more years later. This implies that early performance on segmentation and other speech processing tasks could provide information about the subsequent abilities and skills of individual infants.

Limitations of the Current Study

The current study suffers from a number of limitations that suggest the strong need for prospective study of the potential relationships between early speech segmentation abilities and later language development. First, this study was retrospective in nature, and only pass–fail information regarding infant laboratory performance was available for analysis. Clearly, some children who were labeled as having succeeded may have only demonstrated relatively small preferences for the appropriate stimuli. A study that can link the degree of infant preferences to later development is likely to be more informative.

Next, the retrospective nature of the study limited our hypotheses to those studies that had been originally run, and these studies had not been designed to test the relationship between infant performance and later language ability. It is possible that other infant tasks are equally good or better predictors of later language development. As an example, some theories predict that extrapolating statistical patterns in the input allows infants to perform the kinds of speech segmentation skills that we examined in this study (e.g., Aslin, Saffran, & Newport, 1998; Saffran et al., 1996). The stimuli for such studies are typically synthesized nonsense syllable strings rather than the natural speech samples used in the current set of infant studies. It would be informative to examine what aspects of linguistic and nonlinguistic performance in later childhood might be related to statistical learning abilities in infants. The present study cannot determine whether segmentation abilities or linguistic-specific skills were responsible for infants' later variability in language development or whether some other skill (such as sensitivity to statistical probability) might underlie differences in both abilities. However, our study does at least suggest the need for more specific, hypothesis-driven, prospective examinations of infant speech processing abilities and long-term outcomes. Additionally, none of the infant studies examined here tested infants' abilities to recognize syntactic or morphological patterns in the input, skills that might reasonably relate to later language outcomes. Finally, it is unclear whether the infant's language environment, particularly the relative clarity in the parental input, assists or hinders his or her laboratory performance on the natural speech samples and subsequent long-term developmental outcomes. Recent studies (Liu et al., 2003) have suggested that mothers with larger vowel spaces have infants who are better able to discriminate some fricative contrasts. One might imagine that infants whose parents speak more clearly would show a similar advantage in their segmentation ability and in their vocabulary development; these could, in turn, lead to more advanced language skills at ages 4 to 6 years. A prospective design that included measures of parental input could elucidate the extent to which infants' perceptual performance is shaped by the type of input they experience.

Another limitation of the retrospective design is that it was necessary to truncate the data into the top and bottom 15% of the larger cohort of infants. An examination of infants showing a full range of vocabulary outcomes might strengthen the current findings by showing that they are not simply driven by profiles of children at the extreme boundaries of toddler performance. Similarly, ability to track infants' linguistic development as they are followed in the laboratory may allow us to determine whether some of the speech processing skills lead or follow milestones in language development. Specifically, it can be argued that children who performed better on infant segmentation tasks did so because they were more highly advanced in their language learning in general, rather than being more advanced in their segmentation skills per se.

Finally, because limited numbers of infants participated in the entire range of laboratory tasks over time, it was not possible to determine the consistency of individual infants' performances over time or across tasks. Prospective, longitudinal designs might identify such patterns. The limited number of infants may also have prevented us from seeing some relationships that actually were present. For example, variation in infants' ability to identify prosodic cues to syntax (the prosodic preference studies in Study 1) might in fact be related to later performance. Although some of the children tested in Study 2 had actually been in these prosodic preference studies as infants, the number of participants was too small to identify any relationships. This is unfortunate, as prosodic bootstrapping abilities have been linked theoretically to progress in syntactic development; the use of the MCDI (a primarily lexical assessment) as the outcome measure for Study 1 may not have been a particularly good means of measuring relationships between this skill and later outcomes. The outcome measures tested in Study 2 might have been better able to resolve this issue, had we been able to follow a sufficient number of participants from the prosodic bootstrapping studies.

Despite these limitations, the relationship found here between segmentation and later development is strongly suggestive. We hope they serve as an impetus for future, prospective studies.

Conclusion

The results of this study suggest that speech segmentation ability appears to relate to early expressive language and later full-scale language profiles. Inversely, although success in laboratory speech processing abilities could theoretically reflect generalized intellectual talents, such an association was not found.

The results that we obtained potentially underestimate the true relationship between infant speech segmentation ability and later language development, as none of the children who were assessed in Study 2 demonstrated language ability outside of the normal range. Prospective study of infants at increased risk for language disorder (e.g., because of familial history of SLI) might produce even stronger evidence of the relationship between infant speech processing and later language skill. Recent work by Benasich and Tallal (2002) has supported this hypothesis.

The results of these studies suggest that prospective work to target the predictive relationship between specific laboratory speech processing tasks and later language development would be of great value. In an ideal design, the same children could participate in a number of infant tasks, allowing for the comparison of a number of different types of infant perceptual skills, and allow researchers to examine which skills best predict later development. In some sense, it is encouraging that recent work has identified an array of infant skills that appear to relate to later language outcomes (Benasich & Tallal, 2002; Liu et al., 2003; Molfese & Molfese, 1985, 1997; Trehub & Henderson, 1996). However, the array of skills that have been identified to date is rather broad, and skills include psychophysical, phonetic (both consonant and vowel discrimination), and speech segmentation abilities. It is possible that all of these tap into the same underlying mechanisms or abilities, or that different skills relate to different outcomes. Some skills may be stronger or weaker predictors of outcome. Thus, additional work, particularly of a prospective nature, could greatly enhance our understanding of the prerequisites for successful language acquisition. From an applied perspective, finding tasks that predict patterns of later language acquisition could allow for the development of screening devices geared toward detecting infants at risk for delay or disorder. This in turn could provide a means of identifying and providing help to those infants before serious language deficits become apparent.

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