Infant Pathways to Language

Methods, Models, and Research Disorders

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Psychology Press
Taylor & Francis Group
New York London

Lawrence Erlbaum Associates
Taylor & Francis Group
270 Madison Avenue
New York, NY 10016

Lawrence Erlbaum Associates
Taylor & Francis Group
2 Park Square
Milton Park, Abingdon
Oxon OX14 4RN

Lawrence Erlbaum Associates is an imprint of Taylor & Francis Group, an Informa business

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-13: 978-0-8058-6063-4 (Hardcover)

Library of Congress Cataloging-in-Publication Data

Infant pathways to language : methods, models, and research directions / editors, John Colombo, Peggy McCardle, Lisa Freund.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-8058-6063-4 (hardback : alk. paper)
1. Language acquisition. I. Colombo, John. II. McCardle, Peggy D. III. Freund, Lisa.

P118.I4325 2009
401'.93--dc22 2008025211

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Linking Infant Speech Perception to Language Acquisition

Phonetic Learning Predicts Language Growth

Patricia K. Kuhl

TRODUCTION

ively conference on language processing was held at Massachusetts Institute of chnology (MIT) in 1976, when Denis Klatt, Peter Eimas, and Peter Jusczyk were ll living (Perkell & Klatt, 1976). A specific question raised by Eimas resonated ong the attendees regarding the fast-growing literature on infants' perception speech: Infants show exquisite processing of speech in the first year of life—what e does it play in language development? Does resolution of a 10 ms difference voice onset time (VOT) (to differentiate /ba/ from /pa/; see Eimas, Siqueland, czyk, & Vigorito, 1971) assist the acquisition of language? Jusczyk and Klatt ndered similarly about prosody and its role in language acquisition, and Jus- k's work over the next two decades made that connection (Jusczyk, 1997).

Thirty years after the conference, the question about continuity between ech and language is gaining momentum. Janet Werker's group is examining dlers' use of phonetic detail in their early word representations (Werker & ng, 2005; Werker, this volume); Swingley and Aslin (2002, 2007) pursued question, and so has Kim Plunkett's group (Ballem & Plunkett, 2005). These dies attempt to link speech perception and language acquisition.

Studies in my laboratory have taken a different approach. We have been amining Eimas's question in another way by asking if an infant's early speech rception skill predicts that child's later language ability. A considerable erature indicates an association between deficits in speech perception and pecific language impairment in children, as described herein, but such studies do not prove that a relationship can be established between early speech perception and later language in typically developing children.

Prospective experimental studies conducted in the last few years in my laboratory suggest that infants' early speech perception abilities do predict language growth (Kuhl, Conboy, Padden, Nelson, & Pruitt, 2005; Kuhl et al., 2008; Rivera-Gaxiola, Klarman, Garcia-Sierra, & Kuhl, 2005; Tsao, Liu, & Kuhl, 2004). The data make an important point: What we once considered "noise"—the variance observed in phonetic perception in typically developing infants—is meaningful. Individual differences in infants' speech perception abilities predict the variance in their developmental growth patterns for language.

This chapter summarizes these studies, discusses their implications, and describes the Native Language Magnet-Expanded (NLM-e) model, which explains how linguistic, social, and cognitive skills contribute to the early development of speech perception and speech production and how this early learning affects second language learning.

RETROSPECTIVE STUDIES AND THE ROLE OF PHONETIC PROCESSING IN LANGUAGE IMPAIRMENT

Before any prospective studies demonstrated associations between early speech perception performance and later language abilities, retrospective and concurrent studies revealed a link between reduced phonetic perception and language impairment. Early pioneers in this work were Dennis Molfese and his colleagues who showed, in children between the ages of 3 and 8, that classification into high- versus low-functioning language groups could be predicted by their event-related potential (ERP) responses to speech syllables as newborns (Molfese, 2000; Molfese & Molfese, 1985, 1997). The authors' discriminant function analyses of the children's brain waves as newborns predicted their classification with about 80% accuracy into normal- and low-language performance groups, based on standardized tests.

These data are buttressed by a large body of literature on the phonetic abilities of children diagnosed with reading disorders, learning disabilities, or language impairment in the form of specific language impairment (SLI). Studies confirm that children with reading disabilities show deficits in speech perception when compared with age-matched controls (Reed, 1989). Performance differences between children with dyslexia and controls were reported for tests of speech perception in several studies (Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Manis et al., 1997; Reed, 1989; Werker & Tees, 1987). Similar findings, using both brain and behavioral measures, have been reported for children with various forms of learning disabilities (Bradlow et al., 1999; Kraus et al., 1996).

Links between deficiencies in speech perception and poor language skills are particularly strong in school-age children with SLI (Leonard, McGregor, & Allen, 1992; Stark & Heinz, 1996; Sussman, 1993; Tallal & Piercy, 1974). SLI children perform significantly poorer than age-matched controls in the perception of consonantal acoustic cues such as formant transitions, VOT, and frication noise (Leonard et al., 1992; Tallal & Piercy, 1974; Tallal & Stark, 1981).

PROSPECTIVE STUDIES: ASSOCIATIONS BETWEEN EARLY PHONETIC PERCEPTION AND LATER LANGUAGE

Prospective studies looking at the association between speech discrimination skills in typically developing infants and their future language skills began in my laboratory with the publication of a study showing that vowel discrimination predicted language during the first two years of life. Tsao et al. (2004) tested 6-month-old infants' performance on a standard measure of speech perception, the head-turn (HT) conditioning task, and a simple vowel contrast (the vowels in *tea* and *two*). He assessed the same infants' language skills at 13, 16, and 24 months of age using the MacArthur-Bates Communicative Development Inventory (CDI) (Fenson et al., 1994, 2000). Significant correlations between individual infants' speech perception skills at 6 months and word understanding, word production, and phrase understanding were seen at 13, 16, and 24 months of age. The findings demonstrated, for the first time, that a standard measure of native language speech perception at 6 months of age—the ability to discriminate two vowels—prospectively predicted language outcomes in typically developing infants at three ages over the next 18 months. Parental socioeconomic variables (education, profession, and income level) for both the mother and the father were measured and shown to be unrelated to either the infants' early speech perception skills or their later language abilities (Tsao et al., 2004).

Tsao et al. (2004) argued that phonetic perception per se was related to later language but raised two alternative accounts for the association they observed between native language speech perception and later language—infants' general auditory abilities or general cognitive abilities. Infants who performed better in the phonetic perception tasks might have had better listening skills or might have been cognitively advanced. If so, the observed relationship between speech and language would not link infants' *phonetic abilities* to later language but rather link them to infants' more general hearing and cognitive skills. The next studies in my laboratory examined these alternatives and tested a specific hypotheses generated by the NLM-e model.

PROSPECTIVE STUDIES USING BOTH NATIVE AND NONNATIVE PHONETIC UNITS

Behavioral Studies Examining Native and Nonnative Contrasts

To advance theory, we designed prospective tests using native as well as nonnative phonetic units to examine their predictive value for later language. A revision of the original Native Language Magnet (NLM) model (NLM-e, described following) made specific predictions regarding how native and nonnative perception should relate to later language (Kuhl, 2004; Kuhl et al., 2008). We argue that language acquisition depends on native language *neural commitment*, the development of neural circuitry dedicated to the analysis of the statistical and prosodic patterns in native language speech. The degree to which infants remain able to detect *non*-native phonetic contrasts reflects the degree to which the brain remains in an earlier, more immature state of phonetic perception (Phase 1)—still "open" and uncommitted to native language speech patterns. According to the model, early native language speech perception is required for advancement toward language. Therefore, native perception skill should positively predict language growth. Nonnative phonetic skill, on the other hand, is predicted to correlate negatively with later language learning: An open system reflects uncommitted circuitry.

Kuhl, Conboy, et. al. (2005), conducted the first study using both native and nonnative contrasts. They utilized a standard behavioral measure of speech perception (HT conditioning; see Polka, Jusczyk, & Rvachew, 1995 for procedural details). We tested 20 infants at 7 months of age on the discrimination of the native stop contrast /pa-ta/ and the nonnative Mandarin affricate-fricative contrast / t6ʰi-6i/, counterbalanced across subjects. The Mandarin contrast has been used in previous research in our laboratory (Kuhl, Tsao, & Liu, 2003; Tsao, Liu, & Kuhl, 2006).

The HT task provides a sensitive measure of individual infants' speech perception skill and has been used in many studies. It provides an absolute performance measure, both percent correct and d-prime (d'), for individual infants. The CDI was used to measure language outcomes at 14, 18, 24, and 30 months of age.

Two results were noteworthy. First, there was an association between performance on the native and nonnative contrasts at 7.5 months of age. We found a significant negative correlation for the native and nonnative contrasts ($r = -.481$, $p = .030$, $n = 16$). Infants with higher d′ scores for the English native contrast tended to have lower d′ scores for the Mandarin Chinese nonnative contrast.

Second, we examined whether native or nonnative phonetic perception predicted future language ability and, if so, the direction of the effects. As hypothesized, both native and nonnative d′ measures of speech discrimination at 7 months predicted later language, but differentially. Native language phonetic discrimination was positively correlated with word production at 18 months ($r = .503$, $p = .017$, $n = 17$), sentence complexity at 24 months ($r = .423$, $p = .046$, *n* = 17), and the mean of the three longest utterances (M3L) at 24 months (*r* = .492, *p* = .023, *n* = 17) (Figure 12.1a). In contrast, nonnative language phonetic discrimination in the same infants was negatively correlated with word production at 18 months (*r* = –.507, *p* = .023, *n* = 16), word production at 24 months (*r* = –.532, *p* = .017, *n* = 16), and sentence complexity at 24 months (*r* = –.699, *p* = .001, *n* = 16) (Figure 12.1b).

Vocabulary was measured at all four CDI test ages, allowing examination of the vocabulary growth patterns over time. The differential relationship between native and nonnative phonetic discrimination and vocabulary growth can be seen by comparing vocabulary growth in infants whose d′ scores are above or below the median (Figure 12.2).

Perception of native (Figure 12.2[a]) and nonnative phonetic contrasts (Figure 12.2[b]) at 7 months of age differentially affects the pattern of later vocabulary growth. For the *native* language contrast, infants with a d′ above the median showed faster vocabulary growth than infants with d′ values below the median. For the *nonnative* contrast, the pattern was reversed: Infants with d′ values above the median showed slower vocabulary growth than those with d′ values below the median.

Differences in vocabulary for subjects above and below the d′ median are most pronounced at 18 and 24 months of age. Group effects for the native predictor approach significance at 18 months (*t*(15) = –2.045, *p* = .059). Repeated measures analysis of variance (ANOVA) with the native predictor as a between subjects variable reveals the expected significant age effect for number of words produced (*F*(1,14) = 64.170, *p* = .000). Main effects for the native predictor and the native predictor by age interaction were not significant. Group effects for the nonnative predictor are significant at 24 months (*t*(14) = 2.858, *p* = .013). Repeated measures ANOVA with the nonnative predictor as a between subjects variable also reveals the expected significant age effect for number of words produced (*F*(1,13) = 76.653, *p* = .000). The main effect for the nonnative predictor is significant (*F*(1,13) = 5.046, *p* = .043). Moreover, the nonnative predictor by age interaction is significant (*F*(1,13) = 4.600, *p* = .05).

After 24 months the vocabulary growth differences between native and nonnative predictors dissipate. Given the fact that the infant participants in the study are all typically developing infants who are expected to achieve normal language skills, it is not surprising that the curves merge over time.

Brain Measures of Phonetic Perception as Prospective Predictors of Future Language

We reasoned that the use of brain measures would advance this work because pre-attentive event ERPs reduce the role of cognitive factors, such as attention, on

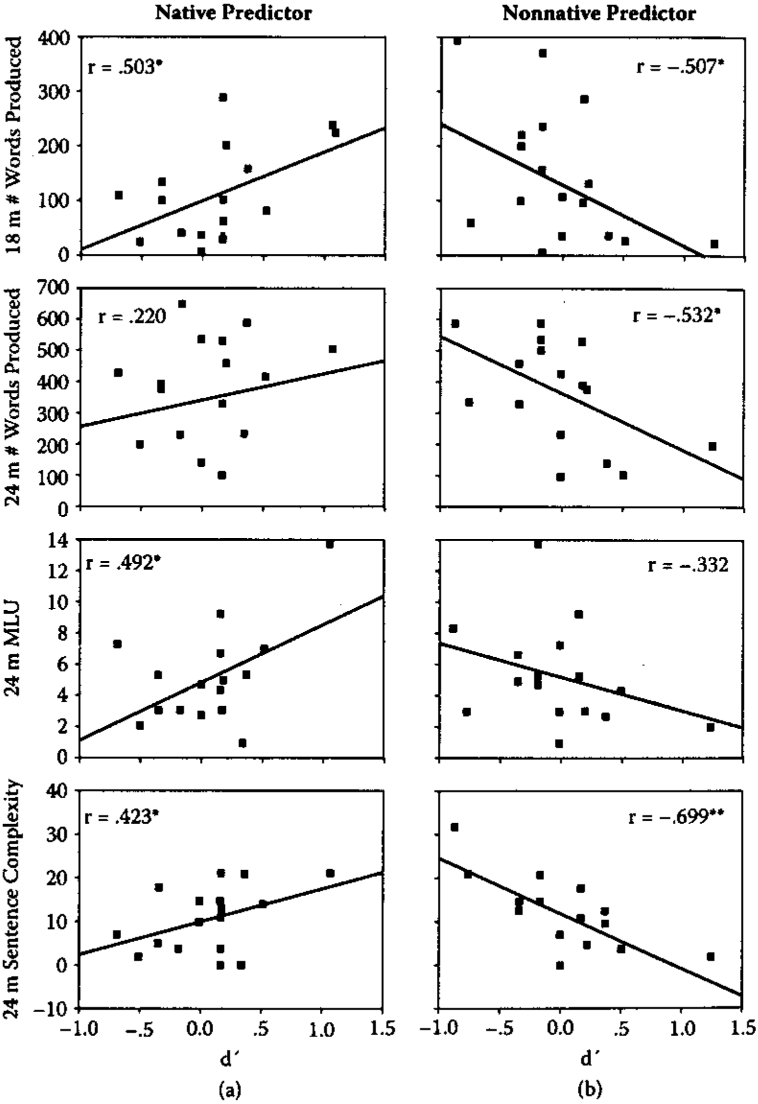
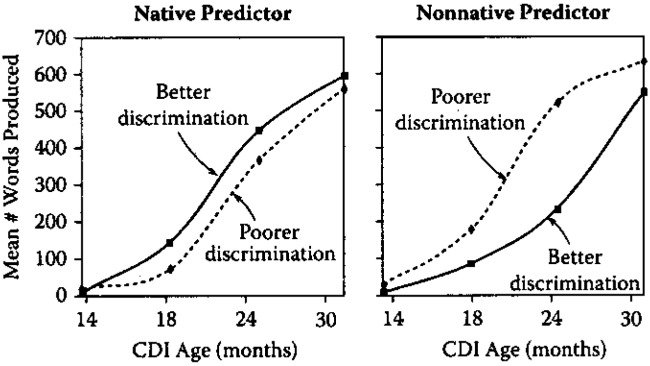


Figure 12.1 Scatterplots showing the relationship between native (left) and nonnative (right) phonetic perception at 7.5 months and language measures taken in the second and third year of life. (Modified from Kuhl, Conboy, et al., 2005, *Language Learning and Development, 1*, 248. With permission.)



(a) (b)

Figure 12.2 Vocabulary growth curves (median number of words produced) for participants with phonetic discrimination at or above (solid line) versus below (dashed line) the median for the native-language contrast (a) and the nonnative language contrast (b). (Modified from Kuhl, Conboy, et al., 2005, *Language Learning and Development, 1*, 249. With permission.)

discrimination. In Kuhl, et al., 2008, we used ERPs to test the same native place contrast (/pa-ta/) and either the nonnative contrast (Mandarin /t6^{h}i-6i/) used in the earlier behavioral tests (Kuhl, Conboy, et al., 2005) or a new nonnative contrast (Spanish voiced-voiceless). Native and nonnative contrasts were presented in counterbalanced order. The use of two nonnative contrasts allowed us to examine whether the predictive relationship we had observed in the behavioral study between early speech and later language would obtain with ERPs and a new nonnative contrast. The classic "oddball" paradigm was used, which has been shown to provide discriminative responses to phonetic changes in the form of mismatch negativity (MMN) in adults (Näätänen et al., 1997) and an MMN-like response in infants (Cheour et al., 1998; Pang et al., 1998; Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005).

ERPs were recorded in 30 (14 female) monolingual full-term infants at 7.5 months of age in response to the native and nonnative phonetic contrasts. In our ERP task (Kuhl et al., 2008), infants listened to the syllables passively while an experimenter entertained them with quiet toys. The oddball paradigm was used with 85% standards and 15% deviants. An EEG was collected continuously with a sampling rate of 250 Hz and was band-pass filtered from 0.1 to 60 Hz at 16 electrode sites using Electro-caps with standard international 10/20 placements. Data collected from eight lateral electrode sites (F7/8, F3/4, T3/4, C3/4) were used in the analysis. Participants heard approximately 500 syllables (standard deviation [SD] = 39) and 60 deviant trials (SD = 14) for each contrast. Mean amplitude of the deviant minus standard difference wave (the MMN) between

300 and 500 ms after the onset of the deviant was measured. Usable ERP data were obtained from 24 of the 30 participants for the native contrast and 22 of the 30 participants for the nonnative contrast (15 to Mandarin and 7 to Spanish). Of the 30 participants, 21 had acceptable ERP data for both native and nonnative contrasts (15 with the Mandarin nonnative contrast and 6 with the Spanish nonnative contrast).

Average waveforms for the standards and deviants obtained for the native and nonnative contrasts at the eight electrode sites were analyzed for each child, and the mean amplitude of the MMN (Näätänen et al., 1997) was calculated at each site. The MMN is a negative wave that is observed in response to the deviant at approximately 250 ms (adults) and slightly later (300–500) for infants (Cheour et al., 1998; Rivera-Gaxiola, Silva-Pereyra, et al., 2005). Better discrimination is indicated by larger amplitudes of the negativity, which can be measured either as a peak value or as a mean amplitude value (Kraus et al., 1996). Separate repeated measures ANOVAs, conducted for each contrast (native, Spanish, and Mandarin), indicated no interactions of stimulus (standard vs. deviant) by hemisphere (left vs. right) by site ($N = 8$) for the native ($F(3,66) = 0.229$, $p = 0.844$, $n = 23$), the Mandarin ($F(3,39) = 0.265$, $p = 0.817$, $n = 14$), or the Spanish ($F(3,18) = 1.309$, $p = 0.305$, $n = 7$) contrast. Based on the broad distributions of the MMNs, a single MMN mean amplitude difference value (deviant minus standard at 300–500 ms) was calculated for each infant's native and nonnative contrast by averaging values across hemisphere and electrode site.

We observed a significant negative correlation between infants' ERPs to native and nonnative contrasts; this was true when the Mandarin nonnative contrast was correlated with the native contrast ($r = -0.741$, $p = 0.046$, $n = 6$), and with the combined data ($r = -0.631$, $p = 0.001$, $n = 21$). Infants with more negative MMN values (indicating better discrimination) for the native /p-t/ contrast tended to have less negative values for the nonnative contrast (either Mandarin or Spanish), while infants with less negative values for the native contrast showed more negative values for the nonnative. This relationship replicates the findings of our previous behavioral study (Kuhl, Conboy, et al., 2005) and extends the pattern of results to a brain measure and a new nonnative contrast.

As we had hypothesized, analysis of the CDI data revealed that both native and nonnative neural measures predicted future language and in opposing directions (Figure 12.3). Better native language discrimination was associated with more advanced language skills measured over the next two years. The native language MMN at 7.5 months significantly predicted the number of words produced at 18 months ($r = -0.430$, $p = 0.020$), the number of words produced at 24 months ($r = -0.611$, $p = 0.001$), higher sentence complexity at 24 months ($r = -0.643$, $p = 0.001$), and a longer M3L at 24 months ($r = -0.632$, $p = 0.001$), as well as at 30 months ($r = -0.487$, $p = 0.017$) (see Figure 12.3[a] for examples). In all cases,

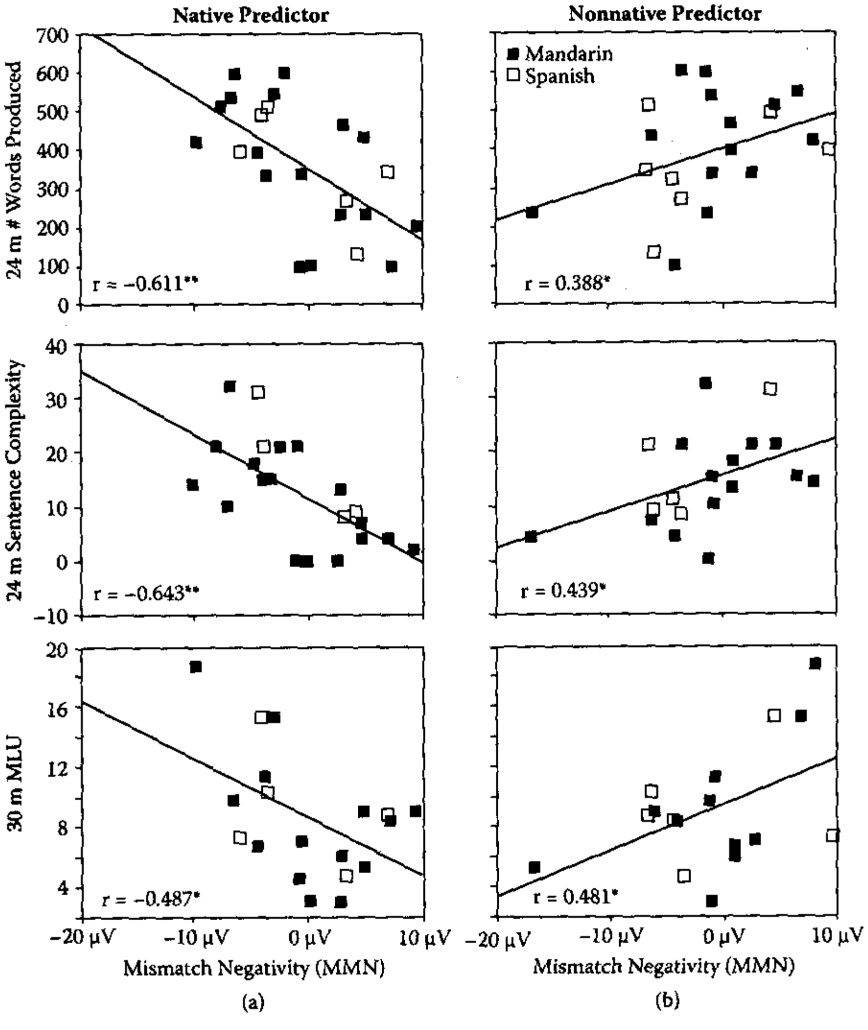


Figure 12.3 Scatterplots show significant correlations between infants' phonetic discrimination, as measured by ERPs (the infant MMN), at 7.5 months for native (left) as opposed to nonnative (right) phonetic contrasts and their later language abilities. (Filled = Mandarin, Open = Spanish). (From Kuhl et al., 2008, *Philosophical Transactions of the Royal Society B*, p. 987. With permission.)

more negative MMN values (indicating better discrimination) are associated with higher language scores, producing negative correlations.

A very different pattern of prediction was observed when infants' MMN measures of nonnative perception were used to predict future language skills

(Figure 12.3[b]). Better discrimination of the nonnative contrast is associated with less advanced language skills. More negative MMNs to nonnative phonetic contrasts (better discrimination) at 7.5 months predicted fewer words produced at 24 months ($r = 0.388$, $p = 0.041$), lower sentence complexity at 24 months ($r = 0.439$, $p = 0.030$), and a shorter M3L at 30 months ($r = 0.481$, $p = 0.025$). Thus, both native and nonnative phonetic units predict later language, but in different directions. This pattern of associations replicates the effects seen in our earlier behavioral study (Kuhl, Conboy, et al., 2005) and extends the pattern to a new nonnative contrast.

Hierarchical Linear Growth-Curve Modeling

Acceleration in expressive vocabulary growth during the second year characterizes learning in many of the world's languages (Bornstein & Cote, 2005; D'Odorico, Carubbi, Salerni, & Calvo, 2001; Fenson et al., 1994; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). To examine whether brain responses to speech sounds at 7.5 months predicted rates of expressive vocabulary development from 14 to 30 months, Kuhl et al. (2008) used the Hierarchical Linear Models (HLMs) program HLM 6 (Raudenbush, Bryk, & Congdon, 2005)(Figure 12.4).

In multilevel modeling, repeated measurements of vocabulary size are used to estimate growth functions for each individual child, and the resultant growth parameters for each individual are modeled as random with variance predicted by a between subjects variable. Inspection of individual children's data indicated that variation across children was observed from 14 to 30 months. Of the 23 children for whom at least 3 data points were available, approximately half ($n = 12$) showed rapid initial growth, reaching close to 400 words or more by 24 months (range, 393–597). From 24 to 30 months, the slopes were flatter in these children, which may be at least partially an artifact of the vocabulary measure (their 30-month vocabulary sizes ranged from 555 to 673 and the CDI ceiling is 680 words). The remaining children evidenced lesser gains in vocabulary size up to 24 months, although their scores were still within the normal range at 24 months (97–343 words) and 30 months (207–678 words).

Separate analyses were conducted for the native and nonnative contrast ERP data in children with artifact-free data at 7.5 months ($n = 24$ and $n = 22$, respectively, with 21 children participating in both analyses). At the first level of each analysis, we estimated individual growth curves for each child using a quadratic equation with the intercept centered at 18 months (due to the small sample sizes we used restricted maximum likelihood). Several reports on expressive vocabulary development in this age range have indicated that quadratic models capture typical growth patterns—both a steady increase and acceleration (Fernald, Perfors, & Marchman, 2006; Ganger & Brent, 2004; Huttenlocher et al., 1991). Centering at 18 months allowed us to evaluate individual differences in vocabulary size at an age

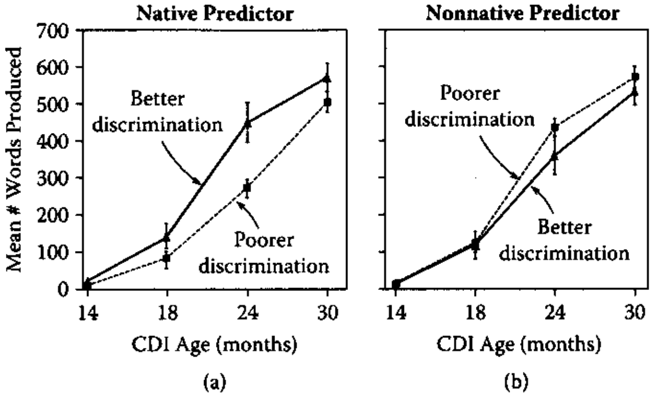


Figure 12.4 A median split of infants whose MMNs indicate better (solid line) versus poorer (dotted line) discrimination of native (a) and nonnative (b) phonetic contrasts is shown along with their corresponding longitudinal growth-curve functions for the number of words between 14 and 30 months of age. (From Kuhl et al., 2008, *Philosophical Transactions of the Royal Society B*, p. 988. With permission.)

that has previously been associated with rapid growth ("vocabulary spurt") as well as differences in rates of growth across the whole period.

For each sample of children, unconditional models indicated individual variation in the random effects for the intercept (18-month vocabulary size), linear slope, and quadratic component. Covariance estimates indicated high degrees of collinearity between the linear and quadratic components for each sample. For both the native and nonnative MMN samples, the intercepts and linear slopes were highly positively correlated at .99, indicating that children with higher 18-month vocabulary sizes tended to have faster growth throughout the 14–30-month period. For both samples, the intercepts and quadratic components were highly negatively correlated (native tau = –.95, nonnative tau = –.99), and the slopes and quadratic components were highly negatively correlated (native tau = –.89, nonnative tau = –.97), which likely reflects the fact that children whose vocabulary sizes reached higher levels by 18 months and had overall faster growth had a leveling off function toward 30 months as they reached the CDI ceiling.

At the second level of analysis, child-level variations in the intercepts (i.e., 18-month vocabulary sizes) and in the slopes of the growth functions were modeled as a function of the 7.5-month native and nonnative MMN values. The quadratic growth-curve model indicated that the average native contrast MMN was significantly related to the intercept (18-month vocabulary size) ($t(22) = -4.15$, $p < 0.001$), the linear slope component ($t(22) = -4.07, p < 0.001$), and the quadratic component of the growth function ($t(22) = 3.32, p = 0.003$).

To illustrate this relationship, Figure 12.4(a) shows the growth patterns for children whose 7.5-month *native* MMNs were below and above the median. The children with better native discrimination skills (more negative mean MMN amplitude values, solid curve) showed faster vocabulary growth. In contrast, children with poorer native discrimination skills (more positive mean MMN values, dotted curve) showed slower growth in the number of words.

As predicted by our hypothesis, the opposite pattern was obtained for the nonnative language contrast (Figure 12.4[b]). Children with better nonnative discrimination skills (more negative mean MMN amplitude values, solid curve) showed slower vocabulary growth, while children with poorer nonnative discrimination skills (more positive mean MMN values, dotted curve) showed faster growth in the number of words. The quadratic growth-curve model showed that the average nonnative contrast MMN values were significantly related to the intercept ($t(20) = 2.27$, $p = 0.03$) and the linear slope component ($t(20) = 2.63$, $p = 0.02$). There was a trend for the interaction between nonnative MMN size and the quadratic component of the growth function ($t(20) = -1.97$, $p = 0.06$). Thus, greater discrimination of the nonnative contrast at 7.5 months was associated with slower vocabulary growth. In contrast, infants showing poorer discrimination evidenced faster growth in vocabulary size.

EXPLAINING THE LINK BETWEEN SPEECH AND LANGUAGE

Our tests show that both native and nonnative phonetic discrimination abilities at around 7 months predict children's language abilities at the age of 30 months. Using both behavioral and brain measures, we show that better *native* phonetic abilities predict faster advancement in language, whereas better *nonnative* phonetic abilities predict slower linguistic advancement.

Additional studies from our laboratory show a similar pattern of prediction for native and nonnative phonetic abilities and later language. Rivera-Gaxiola, Klarman, et al., (2005) measured ERPs in response to native and nonnative English–Spanish contrasts in 11-month-old infants and measured their language skills with the CDI at 18, 22, 25, 27, and 30 months of age. Infants were categorized into two groups depending on the latency and polarity of their *nonnative* contrast responses; infants with prominent negativities between 250 and 600 ms after stimulus onset (good discrimination) at 11 months produced significantly fewer words at each age when compared with infants who did not show this negativity. While infants ERPs were measured differently by Kuhl et al. (in press) and Rivera-Gaxiola, Klarman, et al., (2005), both focus on the degree to which infants produce a strong negativity (indicating good discrimination) in response to a change in phonetic contrasts, and both studies show that good discrimination of the nonnative contrast after 7.5 months of age predicts slower language development.

Using the Rivera-Gaxiola, Klarman, et al. (2005) stimuli and a new double-target behavioral measure to relate concurrent language abilities and speech perception in 11-month-old infants, Conboy, Rivera-Gaxiola, Klarman, Aksoylu, and Kuhl (2005) showed that the degree to which infants' d′ scores to native contrasts exceeded their performance on nonnative contrasts predicted the number of words they comprehended at that age. In other words, a bigger difference between native and nonnative performance predicted faster language growth. This result is consistent with the idea that better performance on native phonetic tasks is an indicator of faster language growth while better performance on nonnative phonetic tasks is an indicator of slower growth in language.

Finally, a study of Finnish 7- and 11-month-old infants replicates this pattern (Silven, Kouvo, Haapakoski, Lahteenmaki, & Kuhl, 2004). Monolingual infants tested on a native Finnish and a nonnative Russian contrast at the two ages and followed up with the Finnish version of the CDI at 14 months showed a significant positive correlation between native language and future language perception at 7 months and a significant negative correlation between nonnative perception at 11 months and future language, a pattern of results that is consistent with what we observed in the English-learning infants (Kuhl, Conboy, et al., 2005; Kuhl et al., 2005).

Thus, a number of studies of typically developing infants between 6 and 12 months of age using different phonetic contrasts in different countries show that better native language speech perception skill, measured either behaviorally or neurally, predicts rapid advancement of language, whereas better nonnative phonetic skill, measured in the same way at the same age, is an indicator of slower language growth. It is important to note that these results are for monolingual infants who have not had any experience with the foreign language being tested. Expectations for bilingual infants are discussed following.

What accounts for the continuity between speech perception and later language? The NLM model (Kuhl, 1992, 1994) has recently been revised. The new Native Language Magnet expanded (NLM-e) model indicates a potential pathway by which phonetic learning advances language development (Kuhl et al., 2008). NLM-e is described briefly here, because it offers an account of the results of our prediction experiments. NLM-e suggests how auditory, cognitive, and social factors interact during phonetic learning, and indicates how early phonetic learning affects second-language learning later in life.

Native Language Magnet-Expanded

The NLM-e model is shown in Figure 12.5. Phase 2, neural *commitment*, is the heart of the model and is most relevant to the experiments discussed here that show a differential relationship between native and nonnative phonetic perception in infancy as predictors of later language. The model is described next.

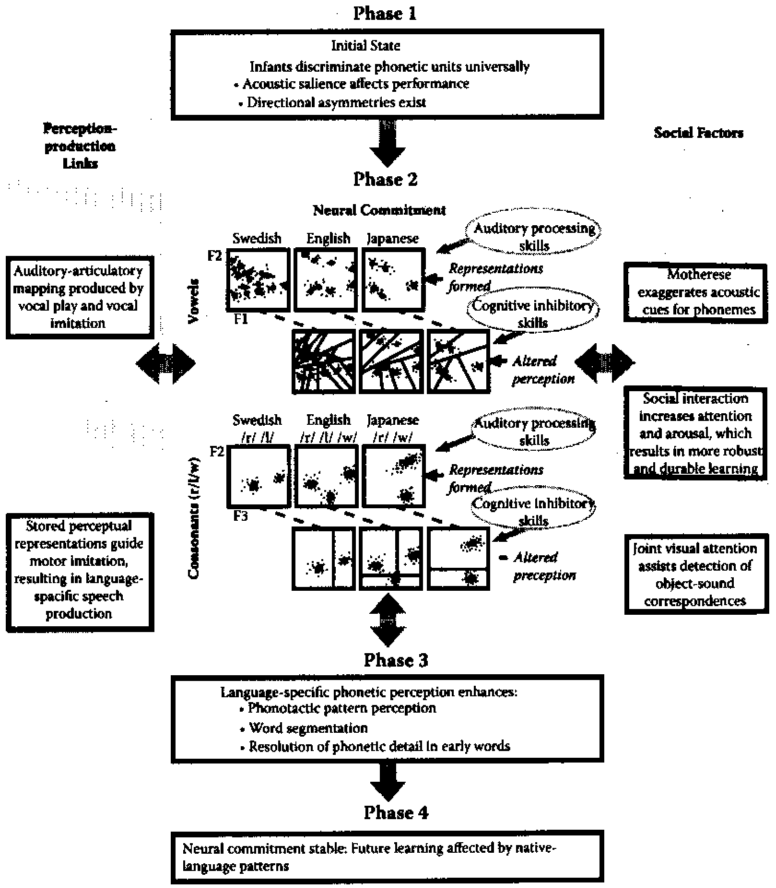


Figure 12.5 NLM-e is shown in four phases (see text for description). The representations of native language input for vowels and consonants are drawn roughly to reflect existing data for Swedish (Fant, 1973; Lacerda, 2006), English (Dalston, 1975; Flege, Takagi, & Mann, 1995; Hillenbrand, Getty, Clark, & Wheeler, 1995) and Japanese (Iverson et al., 2003; Lotto, Sato, & Diehl, 2004). (From Kuhl et al., 2008, *Philosophical Transactions of the Royal Society B*, p. 989. With permission.)

NLM-e: Phase 1

Phase 1 of the model indicates that infants discriminate all phonetic units in the world's languages, though contrasts differ in difficulty and directional effects exist for both consonants (Kuhl et al., 2006) and vowels (Polka & Bohn, 2003). Studies demonstrate that the acoustic salience of a phonetic contrast impacts performance; fricatives, for example, have been shown to be more difficult to discriminate due to their low amplitude (Eilers, Wilson, & Moore, 1977; Kuhl, 1980; Nittrouer, 2001; see also Burnham, 1986). Moreover, studies show that discrimination performance in infants and young children is above chance but far below that shown by adult native listeners (Kuhl et al., 2006; Nittrouer, 2001; Sundara, Polka, & Genesee, 2006). Infants' initial performance thus leaves room for substantial improvement, especially for those contrasts that are acoustically fragile. The model stipulates that in Phase 1, infants' phonetic abilities are relatively crude (see Kuhl, 2000 for cross-species comparisons), reflecting general auditory perceptual constraints or learning in utero (Moon, Cooper, & Fifer, 1993). Infants begin life with a capacity to discriminate the acoustic cues that differentiate phonetic units, an ability that is helpful in Phase 2.

NLM-e: Phase 2

Phase 2 represents the core of the NLM-e model, describing how neural commitment to native language patterns ensues. At this stage in development, phonetic learning is produced through infants' sensitivity to the distributional patterns of language input to the child (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Maye, Werker, & Gerken, 2002) and the exaggerated cues of infant-directed speech (Burnham, Kitamura, & Vollmer-Conner, 2002; Kuhl et al., 1997; Liu, Kuhl, & Tsao, 2003; Liu, Tsao, & Kuhl, 2007). We argue that distributional cues are exaggerated by infant-directed speech, and therefore that the two factors work in concert as agents of change in phonetic perception during Phase 2. Recent data show prominent distributional differences across languages (Werker et al., 2007). As diagrammed in NLM-e, infants form phonetic representations that are stored in memory based on the distributional patterns (exaggerated by infant-directed speech) contained in language input.

Phonetic learning for various contrasts will vary depending on the availability of information about the contrast in language input. As diagrammed, phonetic learning occurs earlier for vowels than consonants (e.g., Best & McRoberts, 2003; Kuhl et al., 1992; Polka & Werker, 1994; Werker & Tees, 1984), a difference that could reflect the availability of exaggerated cues in infant-directed speech—consonants are not as easily exaggerated as vowels, because exaggeration can change the category (e.g., stretching the formant transitions of /b/ eventually produces /w/). Alternatively, there may be differences in the availability or prominence of distributional differences for consonants (e.g., consonants like /th/ occur in function words, which are lower in energy and do not capture infant attention; see Sundara et al., 2006). Individual infants should be affected by the quantity and quality of language input they hear and its exact properties. Detailed studies will need to be done to test these hypotheses.

Our findings suggest that phonetic *learning*, as described in Phase 2—rather than infants' simpler abilities in Phase 1—is the factor associated with advanced language. Infants whose native language perception skills increase are learning from language input, whereas infants who remain good at nonnative perception have not yet begun the phonetic learning process. Group data show that native language speech perception increases between 6 and 12 months of age but also that variability exists (Kuhl et al., 2006; Tsao et al., 2006)—exploiting the variability revealed that infants who learn native language patterns more quickly also advance more rapidly toward language.

What causes the substantial variability we observed in the onset of phonetic learning? One possibility is that maturational factors are responsible. We have argued that the "opening" of the critical period for phonetic learning may reflect a maturational component, and this could vary across infants (Kuhl, Conboy, et al., 2005; Kuhl et al., 2008). Maturation of the human auditory cortex between the middle of the first year of life and 3 years of age shows the development of axons entering the deeper cortical layers from the subcortical white matter—neurofilament-expressing axons appear for the first time in the temporal lobe, with projections to the deep cortical layers of the brain; these axons would provide the first highly processed auditory input from the brainstem to higher auditory cortical areas (Moore & Guan, 2001). The temporal coincidence between this cytoarchitectual change and infants' phonetic learning provides a possible maturational cause for the onset of phonetic learning, and its timing could vary across infants.

Environmental factors could also play a role in the variance seen in the onset of initial phonetic learning. Liu et al. (2003; see also Liu et al., 2007) established an association between mothers' use of the exaggerated pronunciation of speech typical of infant-directed speech and infants' abilities to discriminate phonetic contrasts. The association was observed with two independent samples of mother-infant dyads, one with infants aged 6–8 and a second with infants at 10–12 months of age. We posit, therefore, that infants' phonetic learning skills could also depend on the linguistic environment in which infants are developing; those with richer linguistic environments should advance toward language more quickly.

What role do auditory and cognitive factors play in phonetic learning? Good auditory resolution of the cues that underpin phonetic contrasts is essential to native language phonetic learning. An auditory skill that has been suggested as critical to language is rapid auditory processing (RAP), and relative skill has been shown to predict language disabilities as well as language development in typical children (Benasich & Leevers, 2002; Benasich & Tallal, 2002). It is important to note, however, that a basic auditory skill like RAP cannot explain our differential future language predictions using native and nonnative phonetic contrasts. If better auditory resolution alone were responsible, native and nonnative phonetic perception would predict later language in the same direction. The phonetic prediction effects we have seen must therefore go beyond auditory skills. The NLM model posits a role for auditory resolution in the ability to hear the relevant phonetic differences in native language speech in Phase 2; the fact that infant-directed speech increases the acoustic distance between native language phonetic units should make it easier for infants to do so (Burnham et al., 2002; Kuhl et al., 1997; Liu et al., 2003, 2007).

Similarly, cognitive abilities are linked to various aspects of communicative development (e.g., Bates & Snyder, 1987; Gopnik & Meltzoff, 1987; Thal, 1991; Tomasello & Farrar, 1984), and research suggests that cognitive abilities that tap attentional or inhibitory control are specifically related to performance on nonnative (but not native) speech perception tasks (Conboy, Sommerville, & Kuhl, in press; Diamond, Werker, & Lalonde, 1994; Lalonde & Werker, 1995). Infants' capacity to discriminate nonnative contrasts declines but remains above chance at the end of the first year (Kuhl et al., 2006; Rivera-Gaxiola, Silva-Perayra, et al., 2005; Tsao et al., 2006)—cognitive control may explain how infants refrain from attending to nonnative contrasts that they can discriminate (see Conboy et al., in press for discussion). We note that bilingual children, whose language environments require them to "switch" between languages, develop inhibitory control to a greater extent than monolingual children (Bialystok, 1999; Carlson & Meltzoff, 2008). Early speech perception may be one mechanism through which this "bilingual advantage" emerges.

Social Factors in Phonetic Learning

Social interaction is posited to play a major role in phonetic learning in Phase 2 of NLM-e, placing early language learning in a neurobiological context. Mimicking effects seen in songbirds (see Doupe & Kuhl, 1999 for review), we have shown that social interaction is effective in enhancing phonetic learning in infancy (Kuhl et al., 2003). We used a foreign-language intervention design to examine the role of social interaction in phonetic learning. The study showed that infants exposed to a second language in a social setting for the first time at 9 months showed extraordinary ability to learn over 12 sessions. However, the study also showed that infants did not learn via a conventional TV or audio recording. Infants showed no learning when exposed to the same material. Learning in the social condition was robust and durable. Behavioral tests of infant learning were conducted 2–12 days (median = 6 days) after the final language-exposure session, and ERP tests were conducted between 12 and 30 days (median = 15 days) after the final exposure session, with no observable differences in infant performance as a function of the delay (Kuhl, Coffey-Corina, & Padden, 2007).

In further tests using exposure to Spanish, ERPs were used to test learning of both phonetic units and words in 11-month-old infants after exposure to Spanish speakers in natural play sessions (Conboy & Kuhl, 2007). The results show learning of both Spanish phonemes and words. Moreover, the study was designed to test the hypothesis that social interaction between the infants and their Spanish tutors during the exposure sessions would predict the degree to which individual infants learned phonemes and words (Conboy, Brooks, Taylor, Meltzoff, & Kuhl, 2008). This hypothesis was also confirmed. Infants' overall attention during the exposure sessions and specific measures of shared visual attention between the infant and tutor surrounding the introduction of new toys predicted the degree to which individual infants' ERPs reflected learning of Spanish phonemes and Spanish words. Attention also plays a role in simpler distributional learning experiments in the laboratory (Yoshida, Pons, Cady, & Werker, 2006), and joint visual attention predicts aspects of language, such as the number of words produced (Baldwin, 1995; Baldwin & Markman, 1989; Brooks & Meltzoff, 2005; Meltzoff & Brooks, this volume; Tomasello & Farrar, 1986). The results of Kuhl et al. (2003), Kuhl & Conboy (2007), and Conboy et al. (2008) suggest that social interaction may be critical to phonetic learning in early infancy. In complex natural communicative settings, social interaction may effectively "gate" the computational mechanisms underlying learning (Kuhl, 2007).

The Spanish exposure experiment also provides support for the idea that cognitive control skills can be advanced by exposure to a second language (Bialystok, 2001; Carlson & Meltzoff, 2006). In our study, pre- and post-exposure cognitive control comparisons showed that 12 sessions of Spanish exposure improved cognitive control skills in the infants whose ERPs demonstrated phonetic learning (Conboy & Kuhl, 2007). Understanding how complex systems—linguistic, social, and cognitive—interact in language learning will be a challenge for language research during the next decade.

Exploring how multiple factors affect infants' developing language skills has practical implications. Measures of speech perception, both phonetic abilities and a social interest in speech, may provide early markers of language disorders, such as autism (Kuhl, Coffey-Corina, Padden, & Dawson, 2005). Understanding how early measures, alone and in concert, predict future language will require a comprehensive study that measures simultaneously a variety of skills in infants—basic auditory abilities, cognitive skills, social understanding, phonetic perception, and the ability to detect distributional patterns and statistical cues—in a longitudinal study that examines the individual and joint effects of these factors on language development and on brain development. Multiple factors are expected to play a role in language acquisition (Hollich, Hirsh-Pasek, & Golinkoff, 2000). A comprehensive study using multiple measures on a large cohort of infants is now warranted given the results of these studies showing continuity between early speech perception and later language skills.

NLM-e also indicates a link to speech production that is forged during Phase 2 (see Kuhl et al., 2008, for details). Infants develop connections between speech production and the auditory signals it causes during development as they practice and play with vocalizations and imitate those they hear (Kuhl & Meltzoff, 1996). As speech production improves, imitation of the learned patterns stored in memory leads to language-specific speech production. Our new work on infants uses infant magnetoencephalography (MEG) to explore the linkage between speech perception and production (see also Dehaene et al., 2006; Imada et al., 2006).

By the end of Phase 2, infant perception is altered; native language phonetic learning has begun the neural commitment process, and this propels infants forward toward more complex forms of language.

NLM-e: Phase 3

In Phase 3, enhanced speech perception abilities could advance language by improving three interdependent skills that promote word learning:

1. The detection of phonotactic patterns (Friederici & Wessels, 1993; Mattys, Jusczyk, Luce, & Morgan, 1999)
2. The detection of transitional probabilities between segments and syllables (Goodsitt, Morgan, & Kuhl, 1993; Newport & Aslin, 2004; Saffran, Aslin, & Newport, 1996)
3. The association between sound patterns and objects (Stager & Werker, 1997; Werker, Fennell, Corcoran, & Stager, 2002)

At this stage, phonetic learning would assist the detection of word patterns, and the learning of phonetically close words would be expected to sharpen awareness of phonetic distinctions (see Swingley & Aslin, 2007). Each of these skills—detection of phonotactic patterns, detection of word-like units, and the resolution of phonetic detail in early words—may themselves predict future language, and recent studies provide some retrospective data (Newman, Bernstein Ratner, Jusczyk, Jusczyk, & Dow, 2006).

NLM-e: Phase 4

By Phase 4, the model indicates that analysis of incoming language has produced relatively stable neural representations—that is, new utterances do not cause shifts in the distributional properties coded neurally. In early infancy, neural networks are not stable, and learning is not restricted. Infants are thus capable of learning from multiple languages, as shown in most of the world's countries and also as shown by experimental interventions (Conboy & Kuhl, 2007; Kuhl et al., 2003; Maye et al., 2002). In adulthood, representations are stable, and new learning is more difficult—unlike in infancy, exposure to a new language does not automatically produce learning. The principle underlying the model is that the degree of "plasticity" in learning the phonetics of a second language depends on the stability of the underlying perceptual representations.

The model raises interesting questions about our current language prediction data. Learning and flexibility are in a trading relationship; infants who move more quickly toward native language phonetic learning are becoming less flexible in the process (though early neural commitment to native language patterns is unstable and therefore forms a relatively soft constraint on learning). The model predicts that all learning affects the system's future capacity to learn, and the *effect is predicted to work in both directions; infants who are slower to learn* native language patterns remain more flexible and may more readily learn from second-language exposure.

PREDICTIONS OF THE NLM-E MODEL

Predictions for Bilingual Learners

The NLM-e model predicts that phonetic development follows the same principles for two languages that *it does for a single language. Bilingual infants learn* through the exaggerated acoustic cues provided by infant-directed speech and through the distributional properties of the two languages, as do monolingual infants. Phonetic exaggeration and the distributional properties of the two languages differ, and these properties would provide infants a means of separating the two streams of input.

According to the model, the development of representations in Phase 2 could require a longer period of time for bilingual learners than for the monolingual case. Infants learning two first languages simultaneously might thus be expected to reach the developmental change in perception at a later point than infants learning either language monolingually. Bilingual infants could remain in Phase 2 for a longer period of time because it takes longer to experience enough data from both languages to permit alteration of infant perception; this could depend on factors such as the number of people in the infants' environment producing the two languages in speech directed toward the child and the amount and quality of the infant-directed speech they provide.

As in the case of monolingual exposure, social factors would be expected to play a role in bilingual learning and could in fact be argued to assist learning. In some cases of simultaneous bilingualism, different people speak the two languages to which the infant is exposed. If the social settings in which exposure to the two languages occurs also differ, greater separation between the distributional properties of the two inputs would be achieved. At present there is no evidence of an advantage for such "one person, one language" approaches to bilingual language socialization over approaches in which infants hear both languages from the same people or over situations in which parents frequently code-switch between languages; this is clearly a matter for future research. Code-switching and mixing are common practices in many bilingual communities, and it has been shown that a strict separation of languages is difficult for many families (Goodz, 1989). Even in mixed-language situations, infant-directed speech could exaggerate different aspects of the two languages, assisting infants' mapping of features that are relevant for each of the two languages. We note that the differential effects we observed in predicting future language from infants' early native and nonnative speech perception would also be expected to apply to bilingual infants, though to see the pattern of predictive correlations that we observed, a third language to which the infants have not been exposed would have to be tested. Phonetic contrasts from both languages to which bilingual infants are exposed should correlate positively with later language; a third language, to which infants are not exposed, would be expected to show the opposite pattern.

There are little data on speech perception in infants exposed to two languages simultaneously early in development, and the data are mixed with regard to the question about the timing of the transition in perception. Some studies show later acquisition of language-specific phonetic skills (Bosch & Sebastian-Galles, 2003a, 2003b). This is especially the case when infants are tested on contrasts that are phonemic in only one of the two languages; this has been shown both for vowels (Bosch & Sebastian-Galles, 2003b) and consonants (Bosch & Sebastian-Galles, 2003a). However, other studies report no delay in the development of phonetic skills in the two languages of bilingual infants (Burns, Yoshida, Hill, & Werker, 2007; Sundara, Polka & Molnar, in press). Data from an ERP study of Spanish–English bilingual infants show that at both 6–9 and 9–12 months of age, bilingual infants show negativities in response to both Spanish and English phonetic contrasts (Rivera-Gaxiola & Romo, 2006), distinguishing them from English-learning monolingual infants who no longer respond to the Spanish contrast at the later age (Rivera-Gaxiola, Silva-Pereyra, et al., 2005).

An experiment that will help answer the question with regard to whether bilingual infants take longer to show the developmental transition in phonetic perception is a study on bilingual infants that mirrors our recent studies on monolingual infants (e.g., Kuhl, Conboy, et al., 2005; Kuhl et al., 2008). In the monolingual studies, an increase in native language performance and a decline in nonnative phonetic performance serve to indicate that infants are no longer in the initial phase of development in which all phonetic distinctions are treated similarly (ibid.). To show a decline in bilingual infants a third phonetic contrast, one to which the bilingual children have not been exposed, must be used at the 10–12-month-old age to test the hypothesis that the bilingual infants are no longer in Phase 1 of development. If tests on bilingual infants at 10–12 months reveal the decline typically observed in response to contrasts to which the infant is not exposed, it would signal that bilingual children transition from the initial phase (Phase 1) to Phase 2 at the same point in development as monolingual children. However, if a decline is not observed in the third phonetic contrast, it would indicate that bilingual infants remain in Phase 1 of development—phonetically "open" for a longer period of time, due perhaps to the fact that it takes longer to map two distinct sets of phonetic cues (see Kuhl et al., 2008 for discussion). Such studies are now under way in our laboratory.

Predictions on the Durability and Robustness of Learning

The NLM-e model posits that social interaction results in learning in natural settings that is more robust and durable; in other words, we suggest that learning in social settings is in some sense more potent and enduring. There are two reasons to suggest that social factors affect learning in this way. First, our own data suggest some degree of durability; infants in the Mandarin exposure studies (Kuhl et al., 2003) returned to the laboratory between 2 and 12 days (median = 6 days) after the final exposure session to complete their behavioral Mandarin discrimination tests and between 12 and 30 days (median = 15 days) to complete their ERP tests (Kuhl et al., 2007). Analysis showed that delays of this magnitude had no effect on infants' performance. These data suggest that natural language exposure produced durable effects, with a month-long delay in the measures of learning showing no change.

Infants in the exposure experiment would nonetheless be expected to show a "forgetting function" eventually, because 5 hours of listening experience to a new language would not be sufficient to undo the representations built up over the previous 9 months of life. Memory for the 1-month experience of Mandarin could, however, prompt more rapid learning later in life than would be the case if never exposed to Mandarin. Neural modelers suggest that short-term learning of new phonetic contrasts is initially perceptually separated and therefore produces learning without undoing the representations formed by long-term listening to one's primary language (Vallabha & McClelland, 2007).

Adopting a neurobiological framework, song learning in birds also indicates that social interaction extends the period of learning and produces learning that is more robust and durable. Richer social environments extend the duration of the sensitive period for learning in owls and songbirds (Baptista & Petrinovich, 1986; Brainard & Knudsen, 1998). Social contexts affect the rate, quality, and retention of song elements in songbirds' repertoires (West & King, 1988). The idea that social interaction affects learning in this way can be experimentally assessed by systematically measuring the "forgetting function" for learning under conditions in which the complexity of the input (conversational language from multiple talkers as opposed to 2-minute syllable presentations in the laboratory) as well as the degree of social interaction that the learning paradigm incorporates, will allow us to test this hypothesis.

Predictions Regarding the Mechanism Underlying a "Critical Period" at the Phonetic Level

Language and the "critical period" have long been associated (Bialystok & Hakuta, 1994; Birdsong & Molis, 2001; Flege, Yeni-Komshian, & Liu, 1999; Johnson & Newport, 1989; Lenneberg, 1967; Newport, Bavelier, & Neville, 2001; Weber-Fox & Neville, 1999; Werker & Tees, 2005; Yeni-Komshian, Flege, & Liu, 1999). As described in recent publications, the views laid out in NLM-e may provide a clue to the mechanisms underlying a "critical period" at the phonetic level for language (Kuhl, Conboy, et al., 2005). NLM-e indicates that phonetic learning is associated with a decline in phonetic flexibility, suggesting that *experience*, not simply *time*, is a critical factor driving phonetic learning and perception.

Bruer (2006) recently discussed the need to separate studies that focus on identifying the phenomena and optimum periods of learning in various domains (see also Bateson & Hinde, 1987; Hess, 1973; Lorenz, 1957) from experimental tests that explore the explanatory causal mechanism that underlies a critical period for language. Thus far, our work (Kuhl, Conboy, et al., 2005; Kuhl et al., 2008) has focused on the mechanism question, which requires a different kind of experiment—one that differentiates the role of maturation and the role of experience. Both the maturational view (Bialystok & Hakuta, 1994; Birdsong & Molis, 2001; Flege et al., 1999; Johnson & Newport, 1989; Lenneberg, 1967; Newport et al., 2001; Weber-Fox & Neville, 1999; Yeni-Komshian et al., 1999) and the experience/interference view (Iverson et al., 2003; Kuhl, 1998, 2000, 2004; Seidenberg & Zevin, 2006) are supported by experimental data on first- and second-language learning.

Our data link native language phonetic learning and nonnative decline—both brain and behavioral measures show that the two are significantly negatively correlated, indicating that as native learning ensues nonnative perception is correspondingly reduced in individual infants (Kuhl, Conboy, et al., 2005; Kuhl et al., 2008). What explains this association?

We are exploring two possibilities. If phonetic features form an oppositional network, as is the case in vision, native language phonetic learning could directly inhibit nonnative learning. Testing this hypothesis requires testing a number of different native and nonnative contrasts to examine the generality of our findings. Thus far, the negative correlation has been confirmed for one native contrast (stop consonant place) and two different nonnative contrasts (a Mandarin affricate-fricative and a Spanish voicing contrast), but more contrasts need to be tested. Another possibility is that at a particular point in time infants are sensitive to the distributional cues in language input and this explains the patterns of correlation we have observed. Both explanations would also produce the dissociation between native and nonnative contrasts that we have observed. Further work at the phonetic level will be necessary to determine how learning the set of phonetic contrasts appropriate for one language affects future learning of the phonetic contrasts of a new language, and this will contribute to our understanding of the mechanisms underlying critical period phenomena at the phonetic level of language with potential implications for other levels of language.

CONCLUSIONS

The studies reviewed here suggest continuity between infants' early speech perception skills and their later language abilities. Infants' early abilities to discern differences between native language phonetic contrasts predict their rate of growth for words, phrases, and sentences, suggesting that the variability observed in infants' phonetic skills are not "noise" and instead represent meaningful differences in early linguistic skills that provide a pathway toward language. The fact that our studies show that both native and nonnative speech perception predict later language, but in opposing directions suggests that it is neither infants' general auditory nor their general cognitive skills but instead their phonetic learning abilities that affect language growth. These findings have both theoretical and practical value. A theoretical model, NLM-e, uses the concept of *neural commitment* to explain early speech perception development and makes predictions about bilingual learning and the roles of social and cognitive factors on the mechanisms of phonetic learning. From a practical standpoint, the results suggest that infants' phonetic perception skills may serve as early markers for various disorders of language, including autism, dyslexia, and specific language impairment.

ACKNOWLEDGMENTS

Funding for the research was provided by a grant to the author from the National Institutes of Health (HD37954) and by funding to the University of Washington LIFE Center by the National Science Foundation (NSF) Science of Learning program. This chapter is based on a presentation at a conference sponsored by the Merrill Advanced Studies Institute in Tempe, Arizona, in September 2005 on "Infant Pathways to Language."

REFERENCES

Baldwin, D. A. (1995). Understanding the link between joint attention and language. In C. Moore & Dunham, P.J. (Eds.), *Joint attention: Its origins and role in development* (pp. 131-158). Hillsdale, NJ: Lawrence Erlbaum Associates.

Baldwin, D. A. & Markman, E. M. (1989). Establishing word-object relations: A first step. *Child Development, 60,* 381–398.

Ballem, K. D. & Plunkett, K. (2005). Phonological specificity in children at 1:2. *Journal of Child Language, 32,* 159–173.

Baptista, L. F. & Petrinovich, L. (1986). Song development in the white-crowned sparrow: Social factors and sex differences. *Animal Behavior, 34,* 1359–1371.

Bates, E. & Snyder, L. (1987). The cognitive hypothesis in language development. In I. Uzgiris & J. M. Hunt (Eds.), *Research with scales of psychological development in infancy* (pp. 168–206). Champaign: University of Illinois Press.

Bateson, P. & Hinde, R. A. (1987). Developmental changes in sensitivity to experience. In M. H. Bornstein (Ed.), *Sensitive periods in development* (pp. 19–34). Hillsdale, NJ: Erlbaum.

Benasich, A. & Leevers, H. J. (2002). Processing of rapidly presented auditory cues in infancy: Implications for later language development. In J. Fagan & H. Haynes (Eds.), *Progress in Infancy Research* (Vol. 3, pp. 245–288). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Benasich, A. & Tallal, P. (2002). Infant discrimination of rapid auditory cues predicts later language impairment. *Behavioral Brain Research, 136,* 31–49.

Best, C. & McRoberts, G. (2003). Infant perception of non-native consonant contrasts that adults assimilate in different ways. *Language & Speech, 46,* 183–216.

Bialystok, E. (1999). Cognition and language: Cognitive complexity and attentional control in the bilingual mind. *Child Development, 70,* 636–644.

Bialystok, E. (2001). *Bilingualism in development: Language, literacy, and cognition.* New York: Cambridge University Press.

Bialystok, E. & Hakuta, K. (1994). *In other words: The science and psychology of second-language acquisition.* New York: Basic Books.

Birdsong, D. & Molis, M. (2001). On the evidence for maturational constraints in second-language acquisition. *Journal of Memory and Language, 44,* 235–249.

Bornstein, M. H. & Cote, L. R. (2005). Expressive vocabulary in language learners from two ecological settings in three language communities. *Infancy, 7,* 299–316.

Bosch, L. & Sebastián-Gallés, N. (2003a). Language experience and the perception of a voicing contrast in fricatives: Infant and adult data. In M. J. Solé, D. Recasens, & J. Romero (Eds.), *International Congress of Phonetic Sciences* (pp. 1987–1990). Barcelona, Spain.

Bosch, L. & Sebastián-Gallés, N. (2003b). Simultaneous bilingualism and the perception of a language-specific vowel contrast in the first year of life. *Language & Speech, 46,* 217–243.

Bradlow, A., Kraus, N., Nicol, T., McGee, T., Cunningham, J., Zecker, S., et al. (1999). Effects of lengthened formant transition duration on discrimination and neural representation of synthetic CV syllables by normal and learning-disabled children. *Journal of the Acoustical Society of America, 106,* 2086–2096.

Brainard, M. S. & Knudsen, E. I. (1998). Sensitive periods for visual calibration of the auditory space map in the barn owl optic tectum. *Journal of Neuroscience, 18,* 3929–3942.

Brooks, R. & Meltzoff, A. (2005). The development of gaze following and its relation to language. *Developmental Science, 8,* 535–543.

Bruer, J. T. (in press). Critical periods: Phenomena versus theories. In M. Mody & E. Silliman (Eds.), *Language impairment and reading disability: Interactions among brain, behavior, and experience.* New York: Guilford Press.

Burnham, D. K. (1986). Developmental loss of speech perception: Exposure to and experience with a first language. *Applied Psycholinguistics, 7,* 207–239.

Burnham, D. K., Kitamura, C., & Vollmer-Conner, U. (2002). What's new pussycat? On talking to babies and animals. *Science, 296,* 1435–1435.

Burns, T. C., Yoshida, K. A., Hill, K., & Werker, J. F. (2007). The development of phonetic representation in bilingual and monolingual infants. *Applied Psycholinguisics, 28,* 455–474.

Carlson, S. M, & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science, 11,* 282–298.

Cheour, M., Ceponiene, R., Lehtokoski, A., Luuk, A., Allik, J., Alho, K., et al. (1998). Development of language-specific phoneme representations in the infant brain. *Nature Reviews Neuroscience 1,* 351–353.

Conboy, B. T. & Kuhl, P. K. (2007, April). ERP mismatch negativity effects in 11-month-old infants after exposure to Spanish. Paper presented at the Society for Research in Child Development Biennial Meeting, Boston, MA.

Conboy, B., Brooks, R., Taylor, M., Meltzoff, A., & Kuhl, P. (2008, March). *Joint engagement with language tutors predicts brain and behavioral responses to second-language phonetic stimuli.* Poster presented at the meeting of the International Conference on Infant Studies, Vancouver, BC.

Conboy, B. T., Rivera-Gaxiola, M., Klarman, L., Aksoylu, E., & Kuhl, P. K. (2005). Associations between native and nonnative speech sound discrimination and language development at the end of the first year. In A. Brugos, M. R. Clark-Cotton, & S. Ha (Eds.), *Supplement to the Proceedings of the 29th Boston University Conference on Language Development.* http://www.bu.edu//linguistics/appliedBUCLD/supp29.html

Conboy, B. T., Sommerville, J., & Kuhl, P. K. (in press). Cognitive control factors in speech perception at 11 months. *Developmental Science.*

D'Odorico, L., Carubbi, S., Salerni, N., & Calvo, V. (2001). Vocabulary development in Italian children: A longitudinal evaluation of quantitative and qualitative aspects. *Journal of Child Language, 28,* 351–372.

Dalston, R. M. (1975). Acoustic characteristics of English /w,r,l/ spoken correctly by young children and adults. *Journal of the Acoustical Society of America, 57,* 462–469.

Dehaene-Lambertz, G., Hertz-Pannier, L., Dubois, J., Meriaux, S., Roche, A., Sigman, M., et al. (2006). Functional organization of perisylvian activation during presentation of sentences in preverbal infants. *Proceedings of the National Academy of Sciences USA, 103,* 14240–14245.

Diamond, A., Werker, J. F., & Lalonde, C. (1994). Toward understanding commonalities in the development of object search, detour navigation, categorization, and speech perception. In G. Dawson & K. W. Fischer (Eds.), *Human behavior and the developing brain* (pp. 380–426). New York: Guilford Press.

Doupe, A. J. & Kuhl, P. K. (1999). Birdsong and human speech: Common themes and mechanisms. *Annual Review of Neuroscience, 22,* 567–631.

Eimas, P., Siqueland, E., Jusczyk, P., & Vigorito, J. (1971). Speech perception in infants. *Science, 171,* 303–306.

Eilers, R. E., Wilson, W. R., & Moore, J. M. (1977). Developmental changes in speech discrimination in infants. *Journal of Speech and Hearing Research, 20,* 766–780.

Fant, G. (1973). *Speech sounds and features*. Cambridge, MA: MIT Press.

Fenson, L., Bates, E., Dale, P., Goodman, J., Reznick, J. S., & Thal, D. (2000). Measuring variability in early child language: Don't shoot the messenger. *Child Development, 71*, 323–328.

Fenson, L., Dale, P., Reznick, J., Bates, E., Thal, D., & Pethick, S. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development, Serial, 59*(5, Serial No. 242).

Fernald, A., Perfors, A., & Marchman, V. A. (2006). Picking up speed in understanding: Speech processing efficiency and vocabulary growth across the 2nd year. *Developmental Psychology, 42*, 98–116.

Flege, J. E., Takagi, N., & Mann, V. (1995). Japanese adults can learn to produce English /r/ and /l/ accurately. *Language & Speech, 38*, 25–55.

Flege, J. E., Yeni-Komshian, G., & Liu, S. (1999). Age constraints on second-language acquisition. *Journal of Memory and Language, 41*, 78–104.

Friederici, A. D. & Wessels, J. M. I. (1993). Phonotactic knowledge of word boundaries and its use in infant speech perception. *Perception & Psychophysics, 54*, 287–295.

Ganger, J. & Brent, M. R. (2004). Reexamining the vocabulary spurt. *Developmental Psychology, 40*, 621–632.

Godfrey, J., Syrdal-Lasky, A., Millay, K., & Knox, C. (1981). Performance of dyslexic children on speech perception tests. *Journal of Experimental Child Psychology, 32*, 401–424.

Goodsitt, J., Morgan, J., & Kuhl, P. K. (1993). Perceptual strategies in prelingual speech segmentation. *Journal of Child Language, 20*, 229–252.

Goodz, N. S. (1989). Parental language mixing in bilingual families. *Infant Mental Health Journal, 10*, 25–44.

Gopnik, A. & Meltzoff, A. N. (1987). The development of categorization in the second year and its relation to other cognitive and linguistic developments. *Child Development, 58*, 1523–1531.

Hess, E. H. (1973). *Imprinting: Early experience and the developmental psychobiology of attachment*. New York: Von Nostrand Reinhold Company.

Hillenbrand, J., Getty, L., Clark, M., & Wheeler, K. (1995). Acoustic characteristics of American English vowels. *Journal of the Acoustical Society of America, 97*, 3099–3111.

Hollich, G., Hirsh-Pasek, K., & Golinkoff, R. (2000). Breaking the language barrier: An emergentist coalition model for the origins of word learning. *Monographs of the Society for Research in Child Development, Serial, 65*(3, Serial No. 262).

Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: Relation to language input and gender. *Developmental Psychology, 27*, 236–248.

Imada, T., Zhang, Y. Cheour, M., Taulu, S., Ahonen, A., & Kuhl, P. K. (2006). Infant speech perception activates Broca's area: A developmental magnetoenceohalography study. *Neuroreport, 17*, 957–962.

Iverson, P., Kuhl, P. K., Akahane-Yamada, R., Diesch, E., Tohkura, Y. Kettermann, A., et al. (2003). A perceptual interference account of acquisition difficulties for nonnative phonemes. *Cognition, 87*, B47–B57.

Johnson, J. & Newport, E. (1989). Critical period effects in second language learning: The influence of maturation state on the acquisition of English as a second language. *Cognitive Psychology, 21*, 60–99.

Jusczyk, P. (1997). *The discovery of spoken language*. Cambridge, MA: MIT Press.

Kraus, N., McGee, T., Carrell, T., Zecker, S., Nicol, T., & Koch, D. (1996). Auditory neurophysiologic responses and discrimination deficits in children with learning problems. *Science, 273*, 971–973.

Kuhl, P. K. (1980). Perceptual constancy for speech-sound categories in early infancy. In G. H. Yeni-Komshian, J. F. Kavanagh, & C. A. Ferguson (Eds.), *Child Phonology: Vol. 2. Perception* (pp. 41–66). New York: Academic Press.

Kuhl, P. K. (1992). Psychoacoustics and speech perception: Internal standards, perceptual anchors, and prototypes. In L. A. Werner & E. W. Rubel (Eds.), *Developmental psychoacoustics* (pp. 293–332). Washington, DC: American Psychological Association.

Kuhl, P. K. (1994). Learning and representation in speech and language. *Current Opinion in Neurobiology, 4*, 812–822.

Kuhl, P. K. (1998). The development of speech and language. In T. J. Carew, R. Menzel, & C. J. Shatz (Eds.), *Mechanistic relationships between development and learning* (pp. 53–73). New York: Wiley.

Kuhl, P. K. (2000). A new view of language acquisition. *Proceedings of the National Academy of Sciences USA, 97*(22), 11850–11857.

Kuhl, P. K. (2004). Early language acquisition: Cracking the speech code. *Nature Reviews Neuroscience, 5*, 831–843.

Kuhl, P. K. (2007). Is speech learning "gated" by the social brain? *Developmental Science, 10*, 110–120.

Kuhl, P. K., Andruski, J., Christovich, I., Chistovich, L., Kozhevnikova, E., Ryskina, V., et al. (1997). Cross-language analysis of phonetic units in language addressed to infants. *Science, 277*, 684–686.

Kuhl, P. K., Coffey-Corina, S., Padden, D., & Dawson, G. (2005). Links between social and linguistic processing of speech in preschool children with autism: Behavioral and electrophysiological evidence. *Developmental Science, 8*, 1–12.

Kuhl, P. K., Coffey-Corina, S., & Padden, D. (2007). Effects of short-term foreign-language exposure on brain measures of phonetic perception in infants. Manuscript in preparation.

Kuhl, P. K., Conboy, B. T., Coffey-Corina, S., Padden, D., Rivera-Gaxiola, M., & Nelson, T. (2008). Phonetic learning as a pathway to language: New data and native language magnet theory expanded (NLM-e). *Philosophical Transactions of the Royal Society B, 363*, 979–1000.

Kuhl, P. K., Conboy, B. T., Padden, D., Nelson, T., & Pruitt, J. (2005). Early speech perception and later language development: Implications for the "critical period." *Language Learning and Development, 1*, 237–264.

Kuhl, P. K. & Meltzoff, A. N. (1996). Infant vocalizations in response to speech: Vocal imitation and developmental change. *Journal of the Acoustic Society of America, 100*, 2425–2438.

Kuhl, P. K., Stevens, E., Hayashi, A., Deguchi, T., Kiritani, S., & Iverson, P. (2006). Infants show facilitation for native language phonetic perception between 6 and 12 months. *Developmental Science, 9*, 13–21.

Kuhl, P. K., Tsao, F.-M., & Liu, H.-M. (2003). Foreign-language experience in infancy: Effects of short-term exposure and social interaction on phonetic learning. *Proceedings of the National Academy of Science USA, 100*, 9096–9101.

Kuhl, P. K., Williams, K. A., Lacerda, F., Stevens, K. N., & Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science, 255*, 606–608.

Lacerda, F. (2006). Acoustic analysis of standard central Swedish /r/ and /l/. Manuscript in preparation.

Lalonde, C. & Werker, J. (1995). Cognitive influence on cross-language speech perception in infancy. *Infant Behavior and Development, 18*, 495–475.

Lenneberg, E. (1967). *Biological foundations of language*. New York: John Wiley & Sons.

Leonard, L., McGregor, K., & Allen, G. (1992). Grammatical morphology and speech perception in children with specific language impairment. *Journal of Speech and Hearing Research, 35*, 1076–1085.

Liu, H. -M., Kuhl, P. K., & Tsao, F.-M. (2003). An association between mothers' speech clarity and infants' speech discrimination skills. *Developmental Science, 6*, F1–F10.

Liu, H.-M, Tsao, F.-M., & Kuhl, P. K. (2007). Acoustic analysis of lexical tone in Mandarin infant-directed speech. *Developmental Psychology, 43*, 912–917.

Lotto, A. J., Sato, M., & Diehl, R. (2004). Mapping the task for the second language learner: The case of Japanese acquisition of /r/ and /l/. In J. Slitka, S. Manuel, & M. Matthies (Eds.), *From sound to sense: 50+ years of discoveries in speech communication* (pp. C381–C386). Cambridge, MA: MIT Press.

Lorenz, K. (1957). Companionship in bird life. In C. H. Schiller (Ed.), *Instinctive behavior: The development of a modern concept* (pp. 83–128). New York: International Universities Press.

Manis, R., McBride-Chang, C., Seidenberg, M., Keating, P., Doi, L., Munson, B., et al. (1997). Are speech perception deficits associated with developmental dyslexia? *Journal of Experimental Child Psychology, 66*, 211–235.

Mattys, S., Jusczyk, P., Luce, P., & Morgan, J. (1999). Phonotatic and prosodic effects on word segmentation in infants. *Cognitive Psychology, 38*, 465–494.

Maye, J., Werker, J., & Gerken, L. (2002). Infant sensitivity to distributional information can affect phonetic discrimination. *Cognition, 82*, B101–B111.

Molfese, D. (2000). Predicting dyslexia at 8 years of age using neonatal brain responses. *Brain and Language, 72*, 238–245.

Molfese, D. & Molfese, V. (1985). Electrophysiological indices of auditory discrimination in newborn infants: The bases for predicting later language development? *Infant Behavior and Development, 8*, 197–211.

Molfese, D. & Molfese, V. (1997). Discrimination of language skills at five years of age using event-related potentials recorded at birth. *Developmental Neuropsychology, 13*, 135–156.

Moon, C., Cooper, R. P., & Fifer, W. P. (1993). 2-day-olds prefer their native language. *Infant Behavior & Development, 16*, 495–500.

Moore, J. K. & Guan, Y. L. (2001). Cytoarchitectural and axonal maturation in human auditory cortex. *Journal of the Association for Research in Otolaryngology, 2*, 297–311.

Näätänen, R., Lehtokoski, A., Lennes, M., Cheour, M., Huotilainen, M., Iivonen, A., et al. (1997). Language-specific phoneme representations revealed by electric and magnetic brain responses. *Nature, 385*, 432– 434.

Newman, R. S., Bernstein Ratner, N., Jusczyk, A., Jusczyk, P. W., & Dow, K. A. (2006). Infants' early ability to segment the conversational speech signal predicts later language development: A retrospective analysis. *Developmental Psychology, 42*, 643–655.

Newport, E. L. & Aslin, R. N. (2004). Learning at a distance I. Statistical learning of non-adjacent dependencies. *Cognitive Psychology, 48*, 127–162.

Newport, E. L., Bavelier, D., & Neville, H. J. (2001). Critical thinking about critical periods: Perspectives on a critical period for language acquisition. In E. Dupoux (Ed.), *Language, brain, and cognitive development: Essays in honor of Jacques Mehlter* (pp. 481–502). Cambridge, MA: MIT Press.

Nittrouer, S. (2001). Challenging the notion of innate phonetic boundaries. *Journal of the Acoustical Society of America, 110*, 1598–1605.

Pang, E., Edmonds, G., Desjardins, R., Khan, S., Trainor, L., & Taylor, M. (1998). Mismatch negativity to speech stimuli in 8-month-old infants and adults. *International Journal of Psychophysiology, 29*, 227–236.

Perkell, J. S. & Klatt, D. H. (1976). *Invariance and variability in speech processes.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Polka, L. & Bohn, O. S. (2003). Asymmetries in vowel perception. *Speech Communication, 41*, 221–231.

Polka, L., Jusczyk, P., & Rvachew, S. (1995). Methods for studying speech perception in infants and children. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research* (pp. 49–89). Timonium, MD: York Press.

Polka, L. & Werker, J. F. (1994). Developmental changes in perception of nonnative vowel contrasts. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 421–435.

Raudenbush, S. W., Bryk, A. S., & Congdon, R. (2005). *HLM-6: Hierarchical Linear and Nonlinear Modeling.* Lincolnwood, IL: Scientific Software International, Inc.

Reed, M. (1989). Speech perception and the discrimination of brief auditory cues in dyslexic children. *Journal of Experimental Child Psychology, 48*, 270–292.

Rivera-Gaxiola, M., Klarman, L., Garcia-Sierra, A., & Kuhl, P. K. (2005). Neural patterns to speech and vocabulary growth in American infants. *NeuroReport, 16*, 495–498.

Rivera-Gaxiola, M., & Romo, H. (2006, October). *Infant head-start learners: Brain and behavioral measures and family assessments.* Paper presented at From Synapse to Schoolroom: The Science of Learning. NSF Science of Learning Centers Satellite Symposium, Society for Neuroscience Annual Meeting, Atlanta, GA.

Rivera-Gaxiola, M., Silva-Pereyra, J., & Kuhl, P. K. (2005). Brain potentials to native- and non-native speech contrasts in seven and eleven-month-old American infants. *Developmental Science, 8*, 162–172.

Saffran, J., Aslin, R., & Newport, E. (1996). Statistical learning by 8-month old infants. *Science, 274*, 1926–1928.

Seidenberg, M.S. & Zevlin, J. D. (2006). Connectionist models in developmental cognitive neuroscience: Critical periods and the paradox of success. In Y. Munakata & M. Johnson (Eds.), *Attention & performance XXI: Processes of change in brain and cognitive development* (pp. 585–612). Oxford, England: Oxford University Press.

Silven, M., Kouvo, A., Haapakoski, M., Lahteenmaki, V., & Kuhl, P. K. (2004, July). *Language learning in infants from mono- and bilingual families.* Paper presented at the 18th Biennal International Society for the Study of Behavioral Development (ISSBD) Conference, Ghent, Belgium.

Stager, C. & Werker, J. (1997). Infants listen for more phonetic detail in speech perception than in word-learning tasks. *Nature, 388*, 381–382.

Stark, R. & Heinz, J. (1996). Perception of stop consonants in children with expressive and receptive-expressive language impairments. *Journal of Speech and Hearing Research, 39,* 676–686.

Sundara, M., Polka, L., & Genesee, F. (2006). Language-experience facilitates discrimination of /d-ðethe/ in monolingual and bilingual acquisition of English. *Cognition, 100,* 369–388.

Sundara, M., Polka, L., & Molnar, M. (in press). Development of coronal stop perception: Bilingual infants keep pace with their monolingual peers. *Cognition.*

Sussman, J. (1993). Perception of formant transition cues to place of articulation in children with language impairments. *Journal of Speech and Hearing Research, 36,* 1286–1299.

Swingley, D. & Aslin, R. N. (2002). Lexical neighborhoods and the word-form representations of 14-month-olds. *Psychological Science, 13,* 480–484.

Swingley, D. & Aslin, R. N. (2007). Lexical competition in young children's word learning. *Cognitive Psychology, 54,* 99–132

Tallal, P. & Piercy, M. (1974). Developmental aphasia: Rate of auditory processing and selective impairment of consonant perception. *Neuropsychologia, 12,* 83–93.

Tallal, P. & Stark, R. (1981). Speech acoustic cue discrimination abilities of normally developing and language impaired children. *Journal of the Acoustical Society of America, 69,* 568–574.

Thal, D. (1991). Language and cognition in normal and late-talking toddlers. *Topics in Language Disorders, 11,* 33–42.

Tomasello, M. & Farrar, M. J. (1984). Cognitive bases of lexical development: Object permanence and relational words. *Journal of Child Language, 11,* 477–493.

Tomasello, M. & Farrar, M. J. (1986). Joint attention and early language. *Child Development, 57,* 1454–1463.

Tsao, F.-M., Liu, H.-M., & Kuhl, P. K. (2004). Speech perception in infancy predicts language development in the second year of life: a longitudinal study. *Child Development, 75,* 1067–1084.

Tsao, F.-M., Liu, H.-M., & Kuhl, P. K. (2006). Perception of native and nonnative affricate-fricative contrasts: Cross-language tests on adults and infants. *Journal of the Acoustical Society of America. 120,* 2285–2294.

Vallabha, G. K. & McClelland, J. L. (2007). Success and failure of new speech category learning in adulthood: Consequences of learned Hebbian attractors in topographic maps. *Cognitive, Affective, & Behavioral Neuroscience, 7,* 53–73.

Weber-Fox, C. M. & Neville, H. J. (1999). Functional neural subsystems are differentially affected by delays in second language immersion: ERP and behavioral evidence in bilinguals. In D. Birdsong (Ed.), *Second language acquisition and the critical period hypothesis,* pp. 23–38. Mahwah, NJ: Lawrence Erlbaum and Associates.

Werker, J., Fennell, C., Corcoran, K., & Stager, C. (2002). Infant's ability to learn phonetically similar words: Effects of age and vocabulary size. *Infancy, 3,* 1–30.

Werker, J. F., Pons, F., Dietrich, C., Sachiyo, K., Fais, L., & Amano, S. (2007). Infant-directed speech supports phonetic category learning in English and Japanese. *Cognition, 103,* 147–162.

Werker, J. & Tees, R. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development, 7,* 49–63.

Werker, J. & Tees, R. (1987). Speech perception in severely disabled and average reading children. *Canadian Journal of Psychology, 41,* 48–61.

Werker, J. & Tees, R. C. (2005). Speech perception as a window for understanding plasticity and commitment in language systems of the brain. *Developmental Psychobiology, 46*, 233–234.

Werker, J. & Yeung, H. H. (2005). Infant speech perception bootstraps word learning. *Trends in Cognitive Sciences, 9*, 519–527.

West, M. & King, A. (1988). Female visual displays affect the development of male song in the cowbird. *Nature, 334*, 244–246.

Yeni-Komshian, G., Flege, J. E., & Liu, S. (1999). Pronunciation proficiency in the first and second languages of Korean–English bilinguals. *Bilingualism: Language and Cognition, 3*, 131–150.

Yoshida, K. A., Pons, F., Cady, J. C., & Werker, J. F. (2006, June). Distributional learning and attention in phonological development. Paper presented at International Conference on Infant Studies, Kyoto Japan.