Associations between native and nonnative speech sound discrimination and language development at the end of the first year

Barbara T. Conboy, Maritza Rivera-Gaxiola, Lindsay Klarman, Elif Aksoylu, & Patricia K. Kuhl

University of Washington

1. Introduction

Numerous studies have demonstrated dramatic changes in infant speech perception occurring towards the end of the first year. By 10-12 months of age, infants behaviorally discriminate contrasts that are phonemic in the home language to a greater extent than those that are not phonemic in that language. Younger infants (e.g., 6-8 month-olds) discriminate native and nonnative phonemic contrasts at similar levels, suggesting that language experience exerts an influence on speech perception (e.g., Best, 1994; Kuhl, Tsao & Liu, 2003; Pegg & Werker, 1997; Werker & Tees, 1984). Several of these studies have suggested that the decline in perception of nonnative phonemes cannot be explained merely by lack of exposure to the nonnative language. For example, perception of some nonnative phonemes is maintained throughout the first year, even in the absence of exposure to the language (Best, McRoberts, Lafleur, & Silver-Isenstadt, 1995; Best, McRoberts, & Sithole, 1988; Best & McRoberts, 2003; Polka & Bohn, 1996; Polka, Colantonio, & Sundara, 2001). Other studies have demonstrated that improvement in native language phonetic perception accompanies the decline in nonnative perception (Kuhl, 2004; Kuhl, Tsao, & Liu, 2003; Kuhl, Tsao, Liu, Zhang, & DeBoer, 2000). Studies that have employed brain measures such as event-related potentials (ERPs) also show changes in the processing of both native and nonnative contrasts over the first year of life (Cheour, Ceponiene, Lehtokoski, Luuk, Allik, Alho, & Näätänen, 1998; Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005). Taken together, the results suggest that these changes in speech perception are linked to native language learning.

1.2 Native Language Neural Commitment and Early Language Skills

One proposal offered to explain this developmental change is that language experience results in a *neural commitment* to the features of native-language speech and that this affects language development bidirectionally (Kuhl, 2000; Kuhl, 2004; Kuhl, Conboy, Padden, Nelson, & Pruitt., in press). On this view, native-language learning produces dedicated neural networks that code the patterns of native-language speech and become increasingly less able to accommodate new patterns. Such neural commitment to native-language patterns promotes the acquisition of other linguistic units in the native language (e.g., words) while at the same time causing a decline in the recognition of patterns that do not conform to those learned. Thus, primary language acquisition both drives and depends on native-language neural commitment. Conversely, remaining uncommitted to native-language speech, as reflected by a sustained ability to detect nonnative phonetic contrasts in the absence of language exposure, does not promote acquisition of the native language. Native language phonetic learning reflects neural commitment and is necessary for language acquisition, whereas nonnative perception reflects the degree to which the system remains uncommitted. This view leads to the prediction that infants whose early abilities are better for native as opposed to nonnative contrasts will initially show more rapid language development than infants who continue to show sensitivity to contrasts that are not phonemic in the language to which they have been exposed.

At the same ages that a neural commitment to the native language is noted, infants typically begin to show signs of word comprehension and production (e.g., Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994). Recent studies show that early speech perception measures predict later vocabulary acquisition. Tsao, Liu, & Kuhl (2004) tested 6-month-old infants' performance on the "Conditioned Head Turn" (HT) task (see Kuhl, 1985; Werker, Polka, & Pegg, 1997) using a simple vowel contrast, /i/ vs. /u/. They then assessed the same infants' language skills at 13, 16, and 24 months of age and found significant positive correlations between these later language skills and the speech perception skills at 6 months. These findings suggested a link between speech perception and later language skills, but left open the possibility that underlying cognitive or auditory perception skills were driving the association, rather than speech perception skills *per se*.

Evidence that the link between speech perception skills and later language skills is not simply due to generally better performance in cognitively advanced infants was provided by Kuhl and colleagues (in press), who tested both native- and nonnative-language speech perception in 7.5-month-old infants using the HT procedure, and then assessed vocabulary and other language skills at 14, 18, 24, and 30 months. The results confirmed that both native and nonnative phonetic perception at 7.5 months of age predict future language, but in the opposite direction. Native speech discrimination was positively correlated with later language outcomes, whereas nonnative speech discrimination was negatively correlated with later language scores. Furthermore, Rivera-Gaxiola and colleagues simultaneously tested 11-month-old infants on native and nonnative consonant contrasts using a double-oddball event-related potential (ERP) task, and then examined the same infants' vocabulary skills at 18, 22, 25, 27 and 30 months using the CDI. The analyses showed that differential processing of native and nonnative contrasts predicted vocabulary size at later ages (Rivera-Gaxiola, Klarman, Garcia-Sierra & Kuhl, 2005).

1.3 Questions Addressed in the Present Study

In the present study we used a new version of the HT task to directly compare native vs. nonnative phoneme discrimination skills at 7 and 11 months and explore their association with language ability at 11 months. In our modified version of the HT procedure, native and nonnative target phonemes are contrasted with a single standard shared by both languages within the same test session ('Double-Target' Head Turn Procedure, or DTHT). This procedure allows a tighter comparison between native and nonnative phonetic perception than single-contrast testing designs, by reducing the influence of fatigue and other cognitive factors that can vary across test sessions. It also allows for the testing of a phonetic feature that crosses different phonemic boundaries for English and another language (in this case, Spanish; see Rivera-Gaxiola et al., 2005).

We addressed three questions. First, we asked whether our DTHT procedure would replicate the results of universal speech perception at 7 months vs. language-specific speech perception at 11 months reported in previous studies in which native and nonnative contrasts were tested in separate sessions. If this design yielded the same overall patterns as the previous studies, then the data would add to the evidence that increasing neural commitment to native-language phonetic patterns comes at a cost to perception of nonnative phonetic contrasts. Second, we asked whether the patterns of association between vocabulary growth and native vs. nonnative phonetic perception also hold when a different phonetic feature (i.e., voice onset time) is used. Third, we wanted to know whether the extent to which perception favors native over nonnative speech at 11 months is linked to receptive language abilities at the same age. Such evidence would more strongly support the hypothesis that there are bidirectional influences between vocabulary development and native-language neural commitment at the phonetic level.

Based on previous studies we predicted that 11-month-old infants from monolingual English-speaking families would show better discrimination of the English (native) target than the Spanish (nonnative) target whereas 7-month-old infants would discriminate both the English and Spanish targets at similar levels. We further predicted that individual differences in the degree to which performance on the native exceeds that on the nonnative contrast at both 7 and 11 months would be linked to receptive vocabulary size at 11 months.

2. Methods

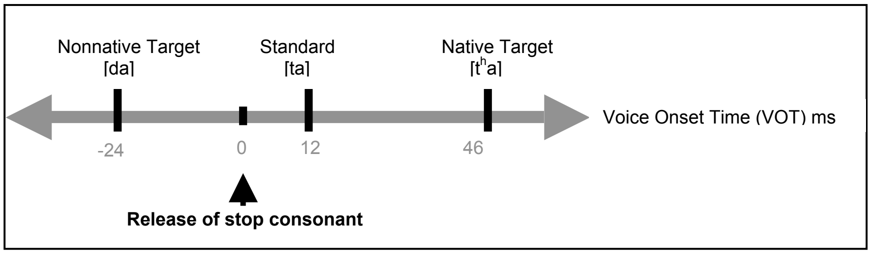
2.1 Participants

Participants were fifty-nine typically-developing infants. Two groups of infants were tested: forty-three 11-month-olds (21 girls; M age = 10.9 months, SD = .097, range = 10.72 to 11.09 months) and sixteen 7-month-olds (8 girls; M age = 7.46 months, SD = .091, range = 7.26 to 7.59 months). All infants were recruited through the University of Washington Infant Subject Pool and met the following criteria: (a) English as the only language spoken in the home and no reported exposure to Spanish; (b) no known physical, sensory or mental handicap; (c) gestational age at birth at 40 ± 3 weeks; and (d) birth weight at least 6 lbs. All infants were reported to have normal hearing at the time of testing.

2.2 Stimuli

Infants were tested on two voice-onset time (VOT) contrasts: English /da/ vs. /ta/ (henceforth, native contrast), and Spanish /ta/ vs. /da/ (henceforth, nonnative contrast) (Figure 1). The same syllable was used for English /da/ and Spanish /ta/ (VOT= +12 ms); this syllable served as the background, or standard stimulus. For the native contrast, the target [t^{h}a] (VOT=+46 ms) was contrasted with the standard, which is identified as /ta/ by adult English speakers (Rivera-Gaxiola, Lara-Ayala, Cadena, & Kuhl, under review; Rivera-Gaxiola, et al., in press; 2005). For the nonnative contrast, the target /da/ (VOT=-24) was contrasted with the standard, which is identified as /da/ by adult Spanish monolingual speakers. The stimuli were natural tokens produced by a female adult bilingual speaker (fundamental frequency 180 Hz) and matched for duration (230 ms), overall contour, intensity, average root mean square power and vowel color. Preliminary studies (Rivera-Gaxiola et al., under review) showed that adult native English speakers detected [t^{h}a] from the standard /ta/s 90% of the time, and the Spanish prevoiced /da/ from the standard /ta/ 7% of the time. Adult native Spanish speakers detected the Spanish /da/ from the standard /ta/ 98% of the time and the [t^{h}a] from /ta/ 85% of the time.

Figure 1: Stimuli used in Double-Target Head Turn task

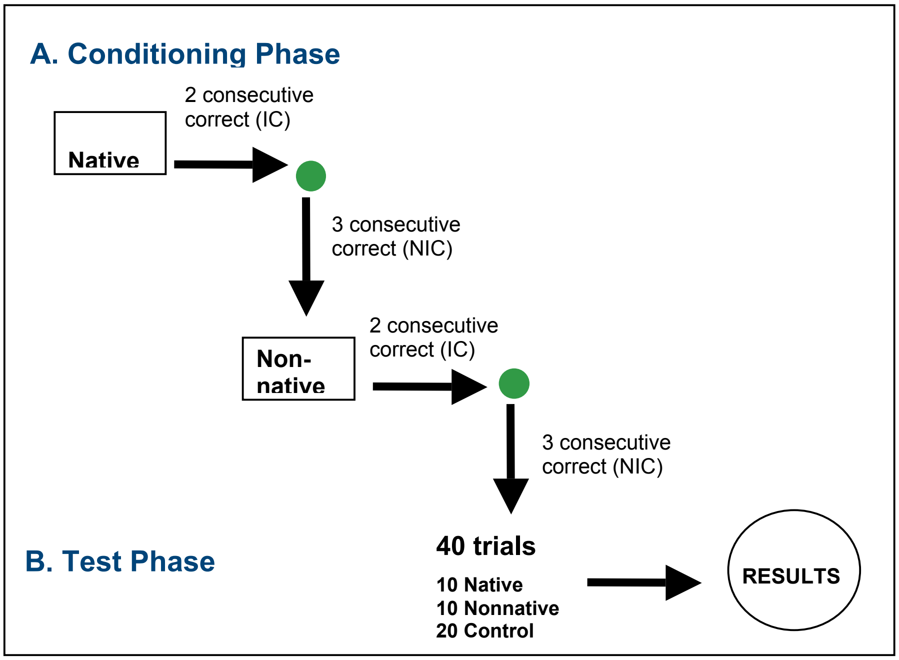


2.3 Phonetic Perception Test

Infants were tested using a modification of the HT procedure (Kuhl, 1985; Werker et al., 1997). In our version of the HT task, participants sit on their parent's lap in a sound-attenuated booth. An assistant, seated to the right, manipulates silent toys to attract the infant's attention. Infants are trained to turn away from the assistant and toward a loudspeaker on their left when they detect a change from the repeating background sound to the target sound. An experimenter observes the infants on a video monitor in a control room during testing and judges the head turn responses. Correct head turn responses are reinforced with presentation of a mechanical toy (e.g., bear tapping on a drum).

The HT procedure consists of a conditioning phase followed by a test phase (Figure 2). In the conditioning phase, all trials are change trials, allowing the infant to learn the association between target sound and visual reinforcement. During initial conditioning, the target sound is presented with an intensity cue (IC) (4 dB louder than the background sound of 65 dB SPL) to draw the infant's attention to the stimulus change. Following two consecutive correct head-turn responses to the target sound in anticipation of the reinforcer, no-intensity cue (NIC) trials are administered until three consecutive correct head-turn responses have been achieved. In the DTHT procedure implemented in the present study, infants were conditioned to the native and nonnative contrasts in separate sessions conducted on the same day or on two consecutive days, and then tested on both contrasts in a single session on a separate day during the same week. For the 11-month-old group, order of conditioning of the native and the nonnative contrasts was counterbalanced across subjects. For the 7-month-old group, all subjects were conditioned to the native contrast first. In the test phase, change (sound change) and control (no sound change) trials occurred with equal probability (50%), and consecutive trials of one type were restricted to three. During change trials, the background sound changed to the target sound for 3 repetitions and head-turn responses during this period were reinforced with a 5 second presentation of the mechanical toy.

Figure 2: Double-Target Head Turn Procedure



During control trials, the background sound was unchanged and infants' head-turn responses were recorded. For change trials, head-turns were scored as "hits" and failure to turn as "misses"; for control trials, head-turns were scored as "false alarms" and failure to turn as "correct rejections." Several measures were taken to control bias: (a) all contingencies and trial selection were under computer control; (b) the parent and assistant wore headphones and listened to music that masked the speech sounds and prevented them from influencing the infants' responses; and (c) the experimenter's headphones, which allowed monitoring of the experimental room, were deactivated during trials so that the experimenter could not hear the stimuli during the trial.

2.4 Data Analysis

Separate sensitivity indices were calculated for each of the contrasts (native and nonnative) using the formulas: *d*'native [= *z* (hit-native) – *z* (false alarm-pooled)] and *d*'nonnative [= *z* (hit-nonnative) – *z* (false alarm-pooled)]. A *d*' difference score was also calculated for each child using the formula: [*d*'native - *d*'nonnative]. Paired t-tests were conducted separately for each age group.

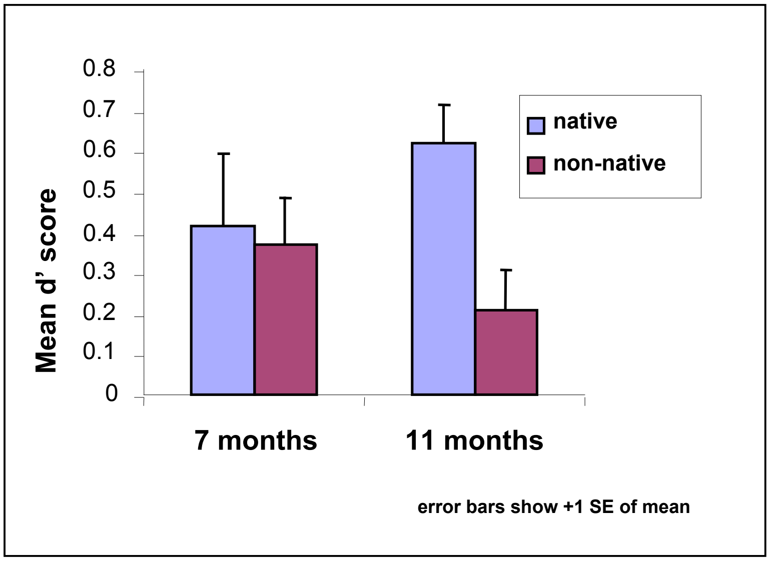
2.5 Language Abilities at 11 Months

Language abilities were assessed using the MacArthur-Bates Communicative Development Inventory: Words and Gestures (CDI), a reliable and valid parent survey for assessing language and communication development from 8 to 30 months (Fenson et al., 1994; Fenson et al., 2000). Parents were instructed to complete the CDI on the day their child reached the target age and return the form. For the present study the "Words Comprehended" score was analyzed. Completed 11-month CDIs were received for 23 infants who were tested on the HT task at 11 months and for 10 of the infants tested at 7 months.

3.0 Results

Results indicated better performance on the native vs. nonnative contrast for the infants tested at 11 months (*d'* =.62*(SD=.65)* vs. .21*(SD=.63); t*=3.56, *df*=42, p<.001)[1], and no difference in performance across contrasts for infants tested at 7 months (d'=.41*(.73)* and .37*(.47)*, respectively) (Figure 3).

Figure 3: Sensitivity to Phonemic Contrasts at 7 and 11 Months



Word comprehension at 11 months was negatively related to performance on the nonnative contrast at the same age (r=-.37, p<.05) but not to performance on the native contrast. The difference between native and nonnative performance at 11 months was positively related to word comprehension (r=.43, p<.05). None of the most advanced infants (word comprehension scores > 100) showed sensitivity to the nonnative contrast, although they did show sensitivity to the native contrast (Figure 4). The 7 month HT scores showed the same trend of association with 11-month word comprehension scores (Figure 5); however, this correlation did not reach statistical significance.

---

[1] An ANOVA conducted on the 11-month data indicated no effects of the order of native vs. nonnative conditioning on the pattern of results; therefore, the 11-month data were pooled.

Figure 4: Relationship of 11m CDI Score to Differential Sensitivity to Native & Nonnative Contrasts at 11m

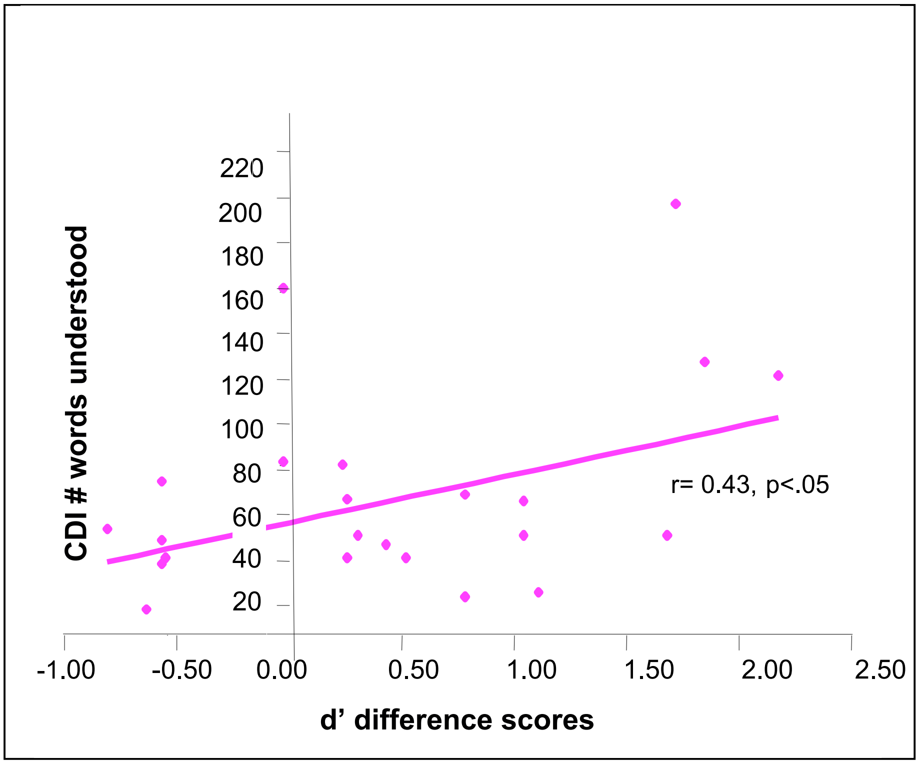
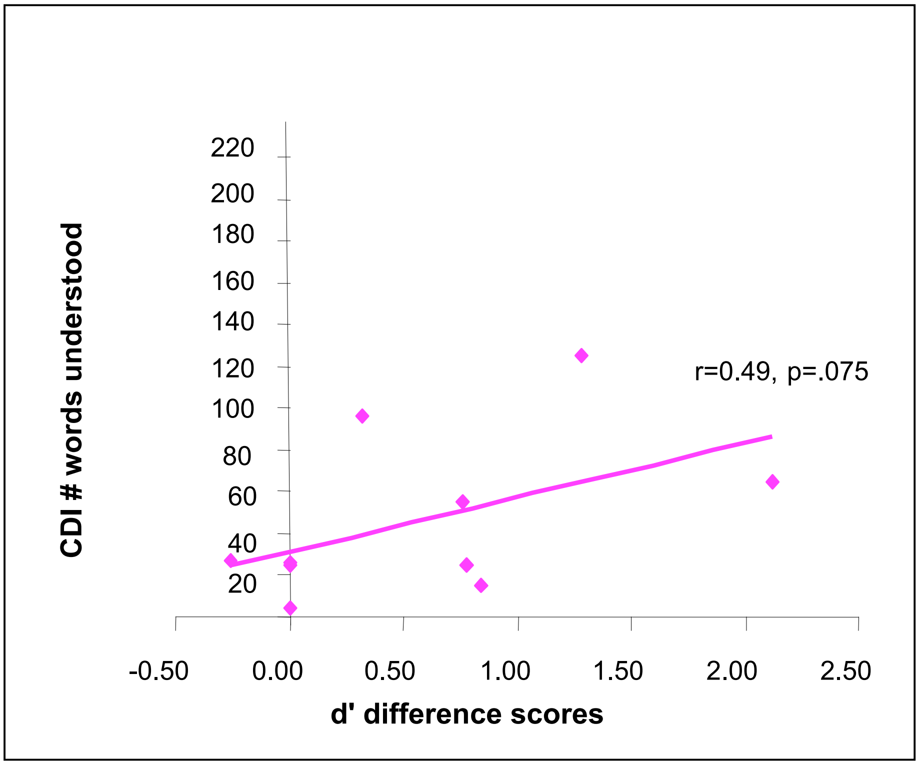


Figure 5: Relationship of 11m CDI Score to Differential Sensitivity to Native & Nonnative Contrasts at 7m



4.0 Discussion

The results of the present study suggest that native and nonnative speech perception predict language development differentially: skill on native speech perception tasks supports language development whereas skill on nonnative-language speech perception tasks does not. Furthermore, they show that the degree to which native phonetic perception is favored over nonnative phonetic perception at 11 months is positively correlated to language comprehension skills at that same age. While these data establish an associative, rather than a causal relationship, they are consistent with the idea that speech perception plays an important role in primary language acquisition. These findings add to a growing body of literature supporting the *Native Language Neural Commitment* (NLNC) hypothesis, which argues that early native-language phonetic skill is necessary for language acquisition, and that the degree to which infants remain good at nonnative phonetic perception indirectly reflects uncommitted circuitry (Kuhl, Coffey-Corina, Padden, Conboy, Rivera-Gaxiola, & Nelson, submitted; Rivera-Gaxiola et al., in press). According to the NLNC hypothesis, in order for language acquisition to ensue, the ability of infants to detect all phonetic contrasts at birth must give way to native language neural commitment (Kuhl et al., in press).

The present findings further show that there is a positive association between the degree to which individual infants' systems are committed to native-language phonetic patterns (the *d'* difference score) and vocabulary skills at the *same* age. These results leave open the possibility that there are bidirectional influences between phonetic perception and vocabulary development. Although previous studies have demonstrated a predictive relationship between native speech perception and later language skills (Tsao et al., 2004; Kuhl et al., in press; Rivera-Gaxiola et al., in press), it is also probable that the broader context of learning a variety of aspects of one's native language influences speech perception skills. The working hypothesis we adopt here is that as native-language learning occurs, the phonetic perceptual system becomes more finely tuned to native language phonetic mapping schemes and less sensitive to alternative (i.e., nonnative) phonetic mapping schemes, and this in turn facilitates other aspects of native-language learning.

Bidirectional influences between speech perception and vocabulary acquisition could take place in a variety of ways. Repeated exposure to the native language could exert bottom-up influences on the perceptual system, in turn facilitating word learning. Between 6 and 9 months of age, infants become increasingly able to use phonotactic patterns to segment words from running speech (Friederici & Wessels, 1993; Mattys, Jusczyk, Luce, & Morgan, 1999). The learning of phonotactic patterns could thus help infants to detect possible word candidates heard in the speech stream. During word learning, infants must learn to associate different sound patterns with particular objects, events, and routines. Although finely-tuned phonetic perceptual abilities may not be used at the earliest stages of word learning (Mills et al., 2004; Stager & Werker, 1997; Werker, Fennell, Corcoran, & Stager, 2002), infants do eventually put such phonetic abilities to use by 17-20 months of age (Bailey & Plunkett, 2002; Stager & Werker, 1997; Swingley & Aslin, 2000; Werker et al., 2002) and possibly as early as 14 months (Swingley & Aslin, 2002).

Vocabulary learning may also influence phonetic abilities. There is evidence that younger infants who have highly advanced word learning skills (i.e., receptive vocabulary size) are better able to use fine phonetic detail in learning new words (Werker et al., 2002). This may be because advanced speech perception skills facilitate word learning skills (Swingley & Aslin, 2002), but it is also possible that growth in the lexicon and subsequently in the density of phonological neighborhoods requires children to increasingly use more detailed phonetic representations in their word learning (Stager & Werker, 1997; see also Bailey & Plunkett, 2002, for a review of these arguments). Experience with words in meaning-based interactions might also enhance speech perception via top-down influences. In a recent study 9-10-month-old infants demonstrated native-like perception of a contrast that was not phonemic in their native language, but was phonemic in a foreign language, after live, interactive exposure to the foreign language (Kuhl, Tsao, & Liu, 2003). In contrast, exposure through videorecordings did not result in such learning. These results suggest that social interaction is crucial for phonetic learning. One important component of live language-learning interactions between infants and adults is joint attention to referents, either through ostensive naming routines or more subtle references to objects and events. Although it is established that joint attention is important for vocabulary acquisition (Baldwin, 1995; Bruner, 1983; Tomasello & Farrar, 1986), it is less clear whether such behaviors also aid phonetic learning. Joint attention might aid phonetic learning via meaning-mediated exposure to vocabulary.

The results of the present study and previous studies suggest that it is speech perception *per se* that predicts language acquisition, rather than general cognitive abilities. As acknowledged by Tsao et al. (2004), better performance on a cognitively demanding task such as the HT task might correlate with better language skills not because of specific speech perception skills but rather because of more general cognitive abilities. The different patterns of association between vocabulary scores and each of the native and nonnative *d'* scores reported in the present study and other studies from our lab (Kuhl et al., in press) suggest that this is not the case. Thus it is not the ability to learn the association between a stimulus and reinforcer, but rather specific speech perception skills that drive the relationship between performance on the speech perception task and native-language vocabulary acquisition. Several studies have demonstrated links between particular cognitive abilities and early language acquisition (Bates, Thal, Finlay, & Clancy, 2003). A more specific cognitive ability, to attend to relevant information while suppressing irrelevant information, may be important for allowing native-language neural commitment to take place. In addition, the learning process itself may help the infant hone such attentional skills. Research from other labs has suggested that infants who show worse performance on nonnative-language speech discrimination tasks at 10-12 months show better inhibitory control on tasks such as the A, not B task (Lalonde & Werker, 1995). Studies are now underway in our lab to test whether the degree to which native perception is favored over nonnative perception correlates with measures of inhibitory control vs. more general problem-solving abilities, and whether these in turn correlate with better language acquisition skills. Such studies will not be able to establish the causality of a connection between the general ability to suppress irrelevant information and a more specific suppression of irrelevant nonnative phonetic detail. However, the direction of causality is not crucial for explaining the NLNC hypothesis. Whether or not the phonetic learning of native-language patterns depends on more general inhibitory control, such learning would make it more difficult to perceive nonnative phonetic categories once learning ensues.

The results of the present study also suggest that infants' general auditory capabilities do not explain the positive correlation between phonetic perception and other aspects of language acquisition. While we do not deny that poor general auditory perceptual skills can play a role in language and reading disorders (Tallal, 1980; Tallal, Stark, & Mellits, 1985; Wright, Lombardino, King, Puranik, Leonard, & Merzenich, 1997), our results show that specific discrimination of native, rather than nonnative, phonetic contrasts is positively associated with other early language skills. It is certainly possible that better vocabulary skills are influenced by better general auditory skills, which are in turn reflected in speech perception tasks. For example, in a recent study of 6-month-old infants with and without positive histories of language impairment, auditory temporal resolution thresholds of individual infants for non-speech stimuli were associated with language comprehension and production scores at the age of two (Benasich & Tallal, 2002). It is not clear, however, why such underlying auditory skills would result in differential performance on native and nonnative speech perception tasks. One possibility for the better performance on the native vs. nonnative contrast at 11 months is that is that infants were attending to the aspiration cue present in the native phonetic contrast ([ta]-[t^{h}a]) rather than the VOT cue, present in both the native and nonnative contrasts. Such an explanation is consistent with Burnham's (1986) proposal that infants increasingly attend to more "robust" cues (in this case, aspiration) and decreasingly attend to "fragile" cues (in this case, VOT). Using the same stimuli in an event-related potential (ERP) double-oddball paradigm, Rivera-Gaxiola and colleagues found that the highly-salient aspiration cue in the lag VOT contrast is processed by infants from Spanish-speaking homes this age, even though the contrast is not phonemic in Spanish (Rivera-Gaxiola et al., under review). In order to rule out the possibility that the 11-month-old pattern of results is due to the saliency of the aspiration cue rather than the effects of language experience on perception of the VOT cue (and that sensitivity to the aspiration cue is in turn linked to better vocabulary skills), we are using the same paradigm with infants being raised in Spanish-speaking environments. However, it is important to note that brain responses to these same stimuli, using the ERP double-oddball paradigm, have also been shown to vary with age in infants from English-speaking environments (Rivera-Gaxiola et al., in press; 2005). Furthermore, other data from our lab show the same pattern of association between native-nonnative speech perception skills and vocabulary development using different phonetic contrasts in similar behavioral tasks (e.g., place of articulation, Kuhl et al., in press), and ERP measures of speech perception (Kuhl et al., submitted; Klarman, Rivera-Gaxiola, Conboy, & Kuhl, 2004; Rivera-Gaxiola et al., in press).

5.0 Conclusions

In summary, we agree with the position that multiple attentional, social, and linguistic cues contribute to infants' word understanding and production in early language development (Hollich, Hirsh-Pasek, & Golinkoff, 2000). The present data show that the associations observed between early speech perception and other aspects of language development cannot be explained by differences in infants' basic auditory or cognitive skills, but rather reflect *learning* in the language domain, which may in turn be mediated by more basic abilities. By using a double-target HT task, we were able to compare native and nonnative speech perception skills measured during the same testing session, on a phonetic feature that crosses categories for both the native and a nonnative language, and then relate the difference in native/nonnative performance to a language comprehension measure collected at the same age. These results are consistent with the view that the shifts in phonetic perception noted during the second half of the infant's first year of life are part of a larger language learning process, and these shifts in turn pave the way for future language acquisition.

6.0 References

Bailey, T., M., & Plunkett, K. (2002) Phonological specificity in early words. *Cognitive Development, 17*, 1265–1282.

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

Bates, E., Thal, D., Finlay, B., & Clancy, B. (2003). Early language development and its neural correlates. In I. Rapin & S. Segalowitz (Eds.), *Handbook of Neuropsychology, Vol. 6, Child Neurology (2nd edition)*. Amsterdam: Elsevier.

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

Best, C.T. (1994). The emergence of native-language phonological influences in infants: A perceptual assimilation model. In J.C. Goodman & H.C. Nusbaum (Eds.), *The Development of Speech Perception: The Transition From Speech Sounds To Spoken Words* (pp. 167-224). Cambridge, MA: MIT Press.

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

Best, C., McRoberts, G., LaFleur, R., & Silver-Isenstadt, J. (1995). Divergent developmental patterns for infants' perception of two nonnative consonant contrasts. *Infant Behavior and Development, 18*, 339-350.

Best, C.T., McRoberts, G.W., & Sithole, N.M. (1988). Examination of perceptual reorganization for non-native speech contrasts: Zulu click discrimination by English-speaking adults and infants. *Journal of Experimental Psychology: Human Perception and Performance, 14*(3), 345-360.

Bruner, J. (1983). *Child's talk.* New York: Norton.

Burnham, D.K. (1986). Developmental loss of speech perception: Exposure to and experience with a first language. *Applied Psycholinguistics, 7*, 207-240.

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

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.

Fenson, L., Dale, P., Reznick, J., Thal, D., Bates, E., Hartung, J., Pethick, S., & Reilly, J. (1993). *MacArthur Communicative Development Inventories: User's guide and technical manual.* San Diego, CA: Singular Publishing Group.

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.

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*.

Klarman, L., Rivera-Gaxiola, M., Conboy, B., & Kuhl, P.K. (2004). Event-related potentials to speech: Individual variation and vocabulary growth. Poster presented at the Society for Neuroscience Annual Meeting, San Diego, October 23-27, 2004.

Kuhl, P.K. (1985). Methods in the study of infant speech perception. In G.Gottlieb & N.Krasnegor (Eds.), *Measurement of audition and vision in the first year of postnatal life: A methodological overview* (pp. 223-251). Norwood, NJ: Ablex.

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

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

Kuhl, P. K , Conboy, B.T., Padden, D., Nelson, T., & Pruitt, J.C. (in press). Early Speech Perception and Later Language Development: Implications for the 'Critical Period'. *Language Learning and Development.*

Kuhl, P. K., Coffey-Corina, S., Padden, D., Conboy, B. T., Rivera-Gaxiola, M., & Nelson, T. (submitted). Infant brain responses to speech suggest a phonetic-level "critical period" mechanism.

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,100*(15), 9096-9101

Kuhl, P. K., Tsao, F.M., Liu, H.M., Zhang, Y. & de Boer, B. (2001). Language/Culture/Mind/Brain: Progress at the margins between disciplines. In A. Damasio et al., Eds.), *The Convergence of Natural and Human Science* (pp. 136-174). New York: The New York Academy of Science.

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

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.

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

Mills, D.L., Prat, C., Zangl, R., Stager, C.L., Neville, H.J., & Werker, J.F. (2004). Language experience and the organization of brain activity to phonetically similar words: ERP evidence from 14- and 20-month-olds. *Journal of Cognitive Neuroscience Volume 16* (8), 1452-1464.

Pegg, J.E. & Werker, J.F. (1997). Adult and infant perception of two English phones. *Journal of the Acoustical Society of America, 102,* 3742-3753.

Polka, L., & Bohn, O.S. (1996). A cross-language comparison of vowel perception in English-learning and German-learning infants. *Journal of the Acoustical Society of America, 100*, 577-592.

Polka, L. Colantonio, C., & Sundara, M. (2001). A cross-language comparison of /d/-/_/ perception: Evidence for a a new developmental pattern. *Journal of the Acoustical Society of America, 109,* 2190-2201.

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

Rivera-Gaxiola, M., Silva-Pereyra, J., & Kuhl, P.K. (2005). Brain potentials to native and non-native speech contrasts in 7- and 11-month-old American infants. *Developmental Science*, 8, 162-172.

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

Rivera-Gaxiola, M., Lara-Ayala, L., Cadena, C., & Kuhl, P.K. (under review). Neural correlates of discrimination of voice-onset time speech contrasts in Mexican 11 month-old infants.

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

Swingley, D., & Aslin, R. N. (2000). Spoken word recognition and lexical representation in very young children. *Cognition,76*, 147–166.

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

Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language, 9*, 182-198.

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., & Mellits, D. (1985). Identification of language-impaired children on the basis of rapid perception and production skills. *Brain and Language, 25*, 314-322.

Tomasello, J. & 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.

Werker, J., Polka, L., & Pegg, J. (1997). The conditioned head turn procedure as a method for testing infant speech perception. *Early Development and Parenting, 6*, 171-178.

Werker, J. F., Fennell, C. E. T., Corcoran, K. M., & Stager, C. L. (2002). Infants' ability to learn phonetically similar words: Effects of age and vocabulary size. *Infancy, 3*, 1–30.

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.

Wright, B., Lombardino, L., King, W., Puranik, C., Leonard, C., & Merzenich, M. (1997). Deficits in auditory temporal and spectral resolution in language-impaired children. *Nature, 387*, 176-178.

Work supported by NIH Grant (HD37954) and NIH UW Research Core Grant, University of Washington P30 DC04661, and also facilitated by NIH P30 (HD02274) from the National Institute of Child Health and Human Development. The authors thank Jessi Moore, Kaite Schoolcraft, Robin Cabiness, and Denise Padden for assistance with data collection, and the parents and infants who participated in this research.