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An association between mothers' speech clarity and infants' speech discrimination skills

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Abstract

The quality of speech directed towards infants may play an important role in infants' language development. However, few studies have examined the link between the two. We examined the correlation between maternal speech clarity and infant speech perception performance in two groups of Mandarin-speaking mother–infant pairs. Maternal speech clarity was assessed using the degree of expansion of the vowel space, a measure previously shown to reflect the intelligibility of words and sentences. Speech discrimination in the infants (6–8 and 10–12-month-olds) was measured using a head-turn task. The results show that mothers' vowel space area is significantly correlated with infants' speech discrimination performance. Socioeconomic data from both parents show that the result cannot be attributed to parental socioeconomic factors. This study is correlational and therefore a causal relationship cannot be firmly established. However, the results are consistent with the view that maternal speech clarity directly affects infants' early language learning.

Language acquisition is driven both by biological mechanisms and environmental adaptations and the interplay between these factors is of strong interest to theorists. Current theories of language acquisition – capitalizing on data indicating that infants acquire phonetic, word and phrase structure information simply by listening to ambient language – suggest that the language addressed to infants may play a critical role in the language acquisition process (Jusczyk; 1997; Kuhl, 2000; Kuhl, Tsao, Liu, Zhang & de Boer, 2001; Snow, 1994).

Systematic investigation of the nature of the speaking style adults use when addressing infants, often termed 'motherese' or infant-directed (ID) speech, shows that it is syntactically and semantically simplified when compared to adult-directed (AD) speech (Cross, 1977; Ferguson, 1964; Snow, 1994). In addition, ID speech has a unique acoustic signature characterized by a higher fundamental frequency (pitch), exaggerated intonation contours, and a slower tempo (Fernald & Simon, 1984; Grieser & Kuhl, 1988; Stern, Spieker, Barnett & Mackain, 1983). The pitch patterns of ID speech attract and hold infant attention, as shown in tests in which infants are given a choice between listening to ID versus AD speech (Cooper & Aslin, 1994; Fernald & Kuhl, 1987).

Recent studies demonstrate that the acoustic modifications in ID speech go beyond the prosodic patterns that capture infant attention. Studies show that the phonetic units in infant-directed speech are exaggerated, making the individual sounds of language more distinct from one another (Burnham, Kitamura & Vollmer-Conna, 2002; Kuhl, Andruski, Chistovich, Chistovich, Kozhevnikova, Ryskin, Stolyarova, Sundberg & Lacerda, 1997). The exaggerated articulations of vowels, for example, 'stretch' the acoustic space that encompasses vowels, enhancing the distinctive features that distinguish them (Kuhl *et al.*, 1997).

Speech modifications in language addressed to children – modifications seen at the syntactic, semantic and phonetic level – appear to simplify and enhance linguistically relevant cues. These studies address Chomsky's (1965) classic 'poverty of the stimulus' argument. They suggest that while adult-directed speech is often ungrammatical and phonetically reduced, infant-directed speech is much less so. However, the fact that adults across many languages and cultures make these modifications when addressing infants and children does not establish whether they have an impact on language learning. Few studies have investigated the potential link between language input to children and children's language development.

Previous studies have reported that the *quantity* of language input from parents (i.e. the number of words that a child hears) is associated with children's vocabulary size at 2 years of age (e.g. Hart & Risley, 1995; Hoff

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& Naigles, 2002; Huttenlocher, Haight, Bryk, Seltzer & Lyons, 1991), though related studies show that maternal socioeconomic status (SES) factors contribute to child vocabulary development at about 2 years of age. These studies indicate that mothers with higher SES tend to talk more frequently to their children than is the case for lower-SES mothers (Bornstein, Haynes & Painter, 1998; Hoff-Ginsberg & Tardif, 1995).

There are currently no data examining whether the *quality* of maternal speech affects infants. The present study addresses this question at the phonetic level of speech. Specifically, we hypothesized that the degree to which mothers expanded their vowel space during infant-directed speech would be strongly associated with infants' performance in tests of speech perception. Our hypothesis is based on two factors. First, a growing number of studies demonstrate that fine-grained analysis of the acoustic-phonetic characteristics of speech, in particular the expanded vowel space area shown in ID speech, provides a highly reliable measure of general speech clarity. Second, we hypothesized that increased speech clarity assists infants in attending to the acoustic events that are critical to the phonetic distinctions contained in their native language.

Regarding the expanded vowel space, Bradlow, Torretta and Pisoni (1996) examined a 2000-sentence database produced by 20 typical speakers. They measured the size of the acoustic vowel space enclosed by the three articulatorily most extreme vowels (/i/, /a/ and /u/) for each talker and examined the relationship between a speaker's vowel space area and the intelligibility of that speaker's sentences. There was a highly significant correlation between the two; speakers who used a larger vowel space produced sentences that were judged by listeners to be more intelligible. The authors concluded that highly intelligible talkers are those with a high degree of articulatory precision for phonetic units. A significant correlation between vowel space area and speech intelligibility has been corroborated in studies examining speakers with speech motor problems (Turner, Tjaden & Weismer, 1995; Weismer, Jeng, Laures, Kent & Kent, 2001). Further studies show that highly intelligible speech (a) contains expanded acoustic differences not only for vowels but also for consonants such as affricates and fricatives, (b) that vowel and consonant expansion is strongly correlated in individual speakers and (c) that vowel space expansion and consonant enhancement together account for a highly significant portion of the variance in listener judgments of intelligibility for speakers of English (Kent, Weismer, Kent & Rosenbek, 1989; Ansel & Kent, 1992) and Mandarin Chinese (Liu, Tseng & Tsao, 2000).

Across studies, the acoustic area encompassing a particular person's vowel space has consistently been shown to be a significant predictor of the perceived clarity of speech. It reflects the articulatory 'working space' used by a specific speaker; a larger working space allows greater articulatory precision and results in robust acoustic differences between phonetic units. These data in turn suggest that ID speech, with its expanded vowel space (Burnham *et al.*, 2002; Kuhl *et al.*, 1997), represents especially 'clear speech' (Kuhl *et al.*, 2001; Lindblom, 1990).

Regarding the potential role of speech clarity in infants' perception of speech, infants in the second half of the first year of life are rapidly acquiring information about the phonetic and phonotactic patterns typical of their native language, a conclusion supported by a wide range of studies (Jusczyk, 1997; Kuhl, 2000; Kuhl, Williams, Lacerda, Stevens & Lindblom, 1992; Werker & Tees, 1999). The perception of phonetic and phonotactic patterns is in turn critical to the discovery of words via statistical learning (Goodsitt, Morgan & Kuhl, 1993; Jusczyk, Friederici, Wessels, Svenkerud & Jusczyk, 1993; Saffran, Aslin & Newport, 1996). Recent studies show that infants in the second half of the first year of life are actively engaged in learning the acoustic characteristics of the phonetic units contained in the language they hear, and can do so even when hearing foreign-language material for the first time. In recent tests we have shown, for example, that 9-month-old infants systematically exposed to conversational foreign language in the laboratory for approximately 5 hours reverse the decline typically seen for a phonetic contrast of that language, indicating infants' sensitivity at this age to the acoustic cues underlying phonetic units (Kuhl, Tsao & Liu, in press). Speech input that is clearly produced should assist this learning process. We therefore predicted that a strong positive correlation would be observed between mothers' vowel space area and infants' phonetic perception.

A correlation between the characteristics of mothers' ID speech and individual infants' speech perception performance does not establish a causal relationship; it forges an associative link. Of importance to the interpretation of such an association are third-factor variables that could potentially mediate the observed relationship. A strength of the present study is the fact that we also measured parental SES factors that might be associated with either or both maternal speech clarity and infant speech perception skill, such as parental education, occupation and income, and determined their relationship to the two principle factors.

The present experiment examined the relationship between maternal speech clarity and infant speech perception performance in two groups of Mandarin Chinese mothers, one group with infants aged 6–8 months and a second with infants aged 10–12 months. Mandarin Chinese, a tonal language, shows the same pattern of

prosodic adjustments in ID speech that have been seen with non-tonal languages (Grieser & Kuhl, 1988; Liu, 2002). The present study was designed to examine whether the vowel space is expanded in ID speech spoken by Mandarin mothers, as shown in previous experiments with English, Swedish and Russian mothers (Burnham *et al.*, 2002; Kuhl *et al.*, 1997), and to determine whether the degree of exaggeration in individual mothers' speech is associated with infants' speech perception skill. The test of infant speech discrimination involved a consonant affricate-fricative contrast shown to be discriminable by Mandarin-learning infants at 7 and 11 months of age (Kuhl *et al.*, 2001).

In brief, mothers' ID and AD speech was measured to examine the feature previously shown to be related to general speech intelligibility, acoustic expansion of the vowel space. Those mothers' infants were then tested to assess phonetic discrimination using a consonant contrast. Finally, the relationship between maternal speech clarity and infant speech perception performance, as well as SES, was examined. We predicted that greater maternal speech clarity would be significantly correlated with higher infant speech perception scores, independent of SES.

Methods

Subjects

The participants were 32 Mandarin-speaking mother–infant dyads tested in Taiwan, 16 with infants aged 6–8 months and 16 with infants aged 10–12 months. Mothers were audiotaped in two speaking situations: (1) while speaking to their infants, and (2) while speaking to another native-speaking adult. Sixteen infants aged 6–8 months (mean = 7.3 months; range = 6.9 to 8.3 months) and 16 infants aged 10–12 months (mean = 11.2 months; range = 10.8 to 12.1 months) participated in the speech perception test. An additional six infants failed to complete testing due to an inability to pass the training, equipment failure or a failure to return for all of the required sessions.

Procedure

Infant-directed and adult-directed speech recordings

The target words selected for speech recording and acoustic analysis were 21 Mandarin Chinese bisyllablic words (3 vowels × 7 tokens) containing the vowels /i/, /a/ and /u/ in the first syllable. The target words were constructed as (C)**V**CV(V), in which the syllable-final vowel could be a monophthong or a diphthong and the tone numeral was attached to the end of each syllable, such as p**a**lʂɚ4 (*bus*) and tɕʰ**i**4pʰau4 (*bubble*). All selected target words were nouns in Mandarin Chinese.

All of the speech samples were recorded using a digital audio tape recorder (SONY TCD-D8) with 16-bit resolution and a sampling rate of 44 kHz. In order to help mothers use the target words in ID and AD conversations, they were provided with toys or pictures that corresponded to the target words. Mothers were instructed to interact and talk as naturally as possible to the adult experimenter and to her infant in a naturalistic face-to-face conversational style, but they were not told the purpose of the research until they finished the two recording sessions. The recording sequence was balanced across participants, so that half of the participants recorded ID speech first, and the other half recorded AD speech first.

Acoustic analysis

Target words were segmented from the original recordings of each speaking condition using a computer-based editing technique. All of the target words, with the exception of those that overlapped with conversation from the experimenter, infant vocalizations or toy noise, were digitally sampled and acoustically analyzed. For each target vowel segment, spectrographic analysis was used to measure the first two formant frequencies (F1 and F2). The acoustic analysis procedure developed in the cross-language study of Kuhl *et al.* (1997) was adapted for use in the present study. Acoustic analysis was conducted using a speech analyzer and software, the KAY Elemetrics' Computerized Speech Laboratory (CSL) 4300 system. Target words were sampled at 20 kHz, 16-bit resolution rate, and low-pass filtered at 10 kHz.

Vowel formant frequencies were measured at the cursor that marked the onset, central and offset positions of a vowel segment. Narrow-band spectrograms, FFT spectra and autocorrelation LPC spectra were used to judge the locations of formants in both AD and ID speech samples. Intra- and inter-rater reliability of acoustic measures was assessed. The experimenter measured 10% of all formant values a second time to examine intra-rater reliability, which was very high (Cronbach α = .94). A second phonetician analyzed 10% of the vowel formant measurements, selected randomly. The inter-rater reliability of the vowel formant analysis procedure was also high (Cronbach α = .90).

The averaged F1 and F2 values of the three vowels of each mother were used to calculate acoustic vowel space areas for each mother in both AD and ID speech conditions. The F1 and F2 of vowels were viewed as Descartes' coordinates on the x-y plane; the area of vowel space

compassing /i/, /a/ and /u/ was equal to the triangular area constructed from the three (F1, F2) pairs of each point vowel in the x-y plane. The vowel space area was calculated using the following equation:

$$\text{Vowel space area} = \text{ABS}\{[F1i*(F2a - F2u) + F1a*(F2u - F2i) + F1u*(F2i - F2a)]/2\},$$

where 'ABS' is the absolute value, 'F1i' is the F1 value of vowel /i/, 'F2a' is the F2 value of vowel /a/, and so on. The vowel space areas of individual speakers were used to compare the articulatory clarity employed by the same speaker when engaged in ID and AD speech. Vowel space areas were calculated from the vowel-midpoint measurements. Previous work shows that ID and AD speech measurements using the initial, central and final vowel locations produce identical results (Kuhl *et al.*, 1997).

Infant speech perception test

We tested the infants using a widely employed procedure for testing infant speech discrimination, the Head-Turn (HT) conditioning procedure (Kuhl, 1985; Werker, Polka & Pegg, 1997). Individual infants' speech perception abilities were assessed using a native consonant contrast, the Mandarin Chinese affricate /tɕʰi/ and fricative /ɕi/ syllables. The stimuli were synthesized using HLsyn speech-synthesis software; they were matched in all acoustic details other than the amplitude rise time that was the critical parameter for distinguishing affricate and fricative consonants for Mandarin Chinese listeners (Tsao, 2001). The amplitude rose by 3 dB SPL over the initial 30 ms for the /tɕʰi/ and over the initial 100 ms for the /ɕi/ syllable. The frication duration was 130 ms, and the total syllable duration of each token was 375 ms. Tokens were equalized in RMS amplitude and were played to infants at a comfortable listening level of approximately 68 dBA through a loudspeaker. The quality of stimuli was judged to be excellent by phoneticians and Mandarin-native adult speakers before the beginning of the experiment. The affricate–fricative contrast used in the present study was successfully discriminated by Mandarin-learning infants at 6–8 and 10–12 months of age in a previous study (Kuhl *et al.*, 2001).

During the test, infants sat on a parent's lap while they watched silent toys manipulated by an assistant seated on their right. Infants were trained to turn away from the assistant and toward a loudspeaker on their left when they detected a change from a repeating background sound (the fricative /ɕ/) to a target sound (the affricate /tɕʰ/). Infants' correct head turns were rewarded with a pleasant visual event (e.g. a black box lit up and a mechanical bear pounded a drum).

The testing procedure consisted of a two-step Training and a Test phase, all of which were under computer control. During the first step in training, an intensity cue (4 dBA higher for the target sound) was used to alert infants to the sound change. When infants produced correct head-turn responses on two consecutive Target trials, the second step of training began, during which the intensity cue was removed. When infants produced correct head-turn responses on three consecutive Target trials without the intensity cue, Training was complete and the Test phase began. During the 30-trial Test phase, both Target (sound change) and Control (no sound change) trials were run with equal probability. Infant head turns were scored on both types of trials. Correct trials included Target trials during which infants produced head turns and Control trials in which infants refrained from head turning; incorrect trials were ones in which infants failed to turn on a Target trial and ones in which they produced a head turn on a Control trial.

During the Test phase, a quantitative measure of speech perception skill, the number of trials needed to reach a pre-established criterion (8 out of 10 consecutive correct responses) was obtained. This measure has often been used to assess infant speech perception (Werker & Tees, 1984; Werker *et al.*, 1997), and recent data show that the number of trials required to reach criterion is a sensitive index of individual differences in speech perception ability (Tsao, Liu & Kuhl, 2003). In addition, infant performance on the entire 30-trial test was used to calculate a percent correct score and a d' measure for each infant.

Parental SES measures

The socioeconomic status (SES) of each of the infants' parents was checked in an SES Background Questionnaire in Chinese that measured parental occupation, income and education. The education level was ranked by the number of years in school, and ranged from elementary school to graduate school. Occupation was ranked on a 9-point scale, from labor (non-technician) to professional (administrator). Annual personal income was ranked on a 5-point scale from low income (NT$360,000 or US$10,588) to high income (NT$1,080,000 or US$31,764).

For the group of 6–8-month-olds, the mothers were typically high school or 4-year-college graduates (M years of education = 13.4 years, SD = 1.76, Range = 9–16 years); the fathers had similar educational background (M = 13.33 years, SD = 3.15, Range = 9–16 years). The majority of the mothers worked as service

providers, and the fathers were mainly technicians. The average annual household income for the subject group was US$30,230 (range = 13,588–55,249), which is close to Taiwan's average household income of US$29,245 (Directorate General of Budget Accounting and Statistics, Taiwan, 2001). The parents' SES backgrounds for the group of 10–12-month-olds were very similar to those of the parents of younger infants. All mothers were high school or 4-year-college graduates ($M = 13.55$ years, SD = 1.86, Range = 12–16 years); fathers had a similar educational background ($M = 13.27$ years, SD = 1.62, Range = 12–16 years). Most of the mothers worked as service providers, and the majority of fathers worked as technicians. The average annual household income of this group was US$31,050 (range = 15,882–61,529).

Results

The acoustic analyses demonstrate that Mandarin mothers of infants who are 6–8 or 10–12 months of age modify their speech at the phonetic level when speaking to their infants. ID speech exhibited acoustically exaggerated vowel articulations when compared with AD speech (see Figures 1, 2), increasing the acoustic distance between vowels in ID speech. There was a significant difference

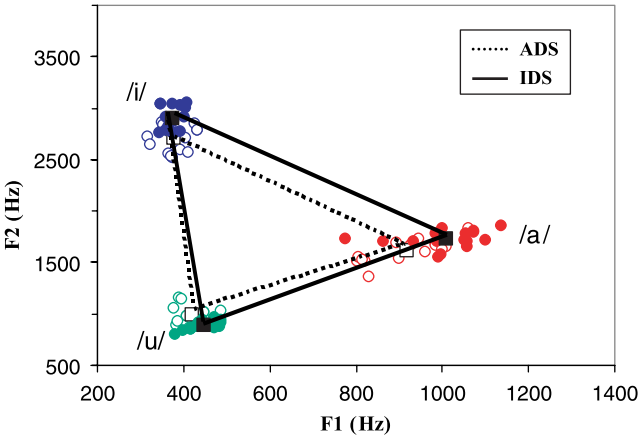

Figure 1 *Data from mothers of 6–8-month-old infants. Vowel spaces formed by the average of the F1 and F2 values for the vowels /i/, /a/ and /u/. Data points represent the mean coordinate of the first two formant frequencies of the vowels /i/, /a/ and /u/ produced by mothers when addressing another adult (open) versus their infant (closed). Each data point represents the average of one mother's vowel productions (14 tokens). An expansion of the vowel space is observed in infant-directed speech (solid line) when compared to adult-directed speech (dashed line).*

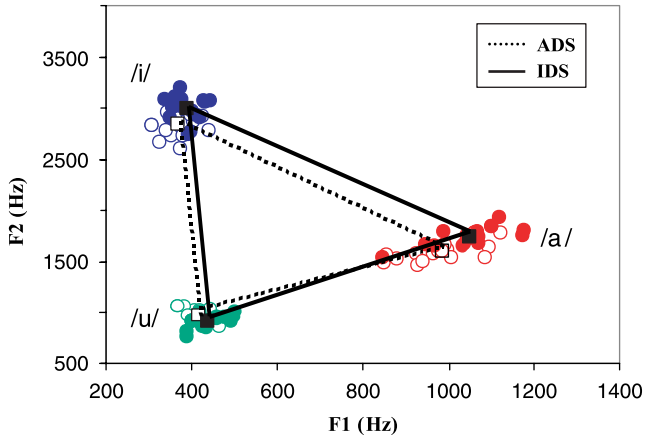

Figure 2 *Data from mothers of 10–12-month-old infants. Vowel spaces formed by the average of the F1 and F2 values for the vowels /i/, /a/ and /u/. Data points represent the mean coordinate of the first two formant frequencies of the vowels /i/, /a/ and /u/ produced by mothers when addressing another adult (open) versus their infant (closed). Each data point represents the average of one mother's vowel productions (14 tokens). An expansion of the vowel space is observed in infant-directed speech (solid line) when compared to adult-directed speech (dashed line).*

in vowel space area between ID and AD speech, as shown in one-way repeated-measures ANOVAs, for mothers of the 6–8-month-old infants, $F(1, 15) = 65.22$, $p < .001$, and for mothers of the 10–12-month-old infants, $F(1, 15) = 20.20$, $p < .001$. At the level of individual subjects, the results demonstrated that all mothers of the 6–8-month-old infants (16 out of 16) showed vowel space expansion in ID speech compared to AD speech ($p < .01$, binomial test); in mothers of the 10–12-month-olds, vowel space expansion in ID speech compared to AD speech was observed for the majority of the mothers (13 out of 16) ($p < .05$, binomial test). These results replicate previous studies on English-, Swedish- and Russian-speaking mothers (Burnham *et al.*, 2002; Kuhl *et al.*, 1997).

The results of the infant speech perception tests showed the expected increase in infants' overall discrimination scores with increasing age. At 6–8 months, performance ranged from 53% to 73% ($M = 61.69\%$); in signal detection analyses, d' scores ranged from .19 to 1.40 ($M = .66$). At 10–12 months of age, discrimination scores ranged from 53% to 80% ($M = 68.25\%$); in signal detection analyses, d' scores ranged from .15 to 1.76 ($M = 1.02$). This increase was significant, $t(30) = 2.66$, $p < .012$.

The trials-to-criterion measure, used in the correlational analysis, ranged from 8 to 30 trials ($M = 16.71$,

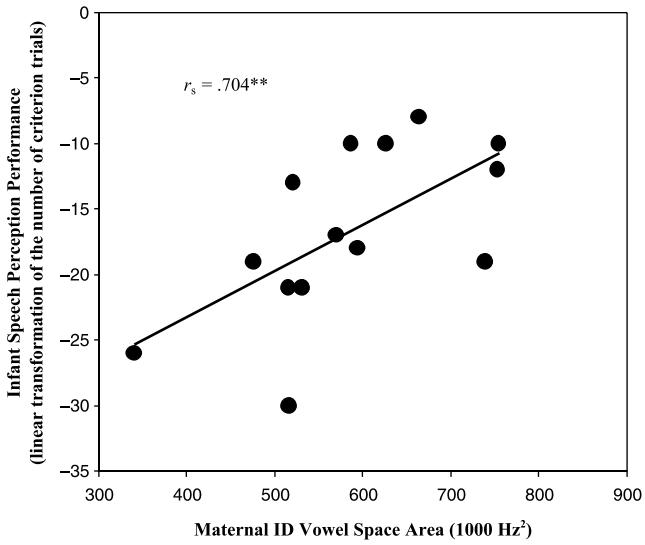

Figure 3 *Scatter plot showing the relationship between performance in a test of speech perception by individual 6–8-month-old infants and their mother's speech clarity (see text for details). The results show that mothers with clearer speech have infants with better speech perception performance.*

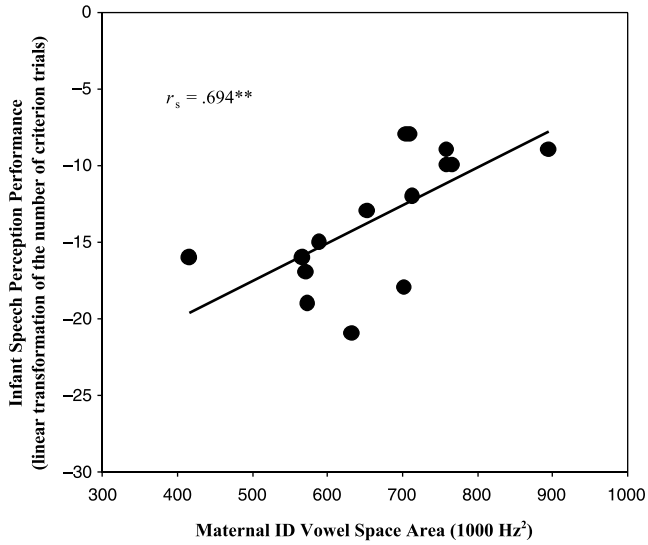

Figure 4 *Scatter plot showing the relationship between performance in a test of speech perception by individual 10–12-month-old infants and their mother's speech clarity (see text for details). The results show that mothers with clearer speech have infants with better speech perception performance.*

SD = 6.56) for the 6–8-month-old infants and from 8 to 21 trials ($M = 13.33$, SD = 4.42) for the 10–12-month-old infants. Note that a low number of criterion trials indicates better performance. The number of criterion trials required was transformed (multiplied by −1) for further analysis so that better performance was indicated by a higher score.

The correlation analysis demonstrated a strong association between the size of the vowel space in maternal ID speech and infants' performance on the speech perception test. A larger vowel space area used by the infant's mother in ID speech was strongly associated with better speech perception performance. This was true both for mother–infant pairs at 6–8 months of age, $r_s = .704$, $p < .005$, and for mother–infant pairs at 10–12 months of age, $r_s = .694$, $p < .004$ (see Figures 3 and 4). The observed association between maternal speech clarity and infant speech perception was not attributable to maternal or paternal SES. At 6–8 months, the correlations between mother's speech and her education ($r_s = .204$, $p > .1$), occupation ($r_s = .006$, $p > .1$) and income ($r_s = -.190$, $p > .1$) failed to reach significance. A similar pattern was seen at 10–12 months of age; the correlations between mother's speech and her education ($r_s = .279$, $p > .1$), occupation ($r_s = .201$, $p > .1$) and income ($r_s = -.051$, $p > .1$) were not significant. Correlations between maternal and paternal SES and infants' speech perception abilities were similarly nonsignificant ($p > .1$ in all cases).

When both mothers' vowel space area and parental SES measures were taken into account in predicting infants' discrimination performance using a stepwise multiple regression model, only mothers' vowel space area was a significant predictor. Mothers' vowel space area accounts for 39.7% of the variance in 6–8-month-old infants' phonetic discrimination performance, $F(1, 13) = 7.893$, $p < .016$, and for 42.0% of the variance in 10–12-month-old infants' phonetic discrimination performance, $F(1, 14) = 9.399$, $p < .004$.

Discussion

The results of this experiment demonstrate a highly significant positive correlation between maternal speech clarity and infant speech perception performance. The results were replicated in two groups of mothers, those with infants at 6–8 months of age and those with infants at 10–12 months of age. Moreover, the results showed that the observed association could not be attributed to parental socioeconomic factors. Neither maternal nor paternal socioeconomic variables were significantly correlated with mothers' speech clarity or infants' speech perception performance.

The findings provide the first evidence of a link between the quality of maternal speech input at the phonetic level and infants' perception of the phonetic units of language. Although the link between maternal speech clarity and infants' phonetic performance is

correlational, the most obvious possible mediating factor, SES variables such as parental education, income and occupation, were eliminated.

While socioeconomic factors cannot account for the observed association, other factors cannot be ruled out by the present study. One might argue, for example, that mothers with higher cognitive ability enunciate more clearly, and that their infants, inheriting these skills, perform more accurately in a speech discrimination task that requires cognitive ability. As previously discussed, however, variables typically associated with cognitive ability, such as educational level, income and occupation, did not correlate with the maternal speech measures.

Similarly, one could entertain the hypothesis that general sensory ability explains both maternal speech clarity and infant auditory perception of speech. It is possible that an individual infant's phonetic perception relies to some degree on basic auditory skills. However, there is no evidence that speaking clearly is related to hearing sensitivity in adults. Speech production is equivalent over a large range of hearing ability; only when hearing is severely impaired does speech production erode in quality (e.g. Elssmann & Maki, 1987; Yoshinaga-Itano & Sedey, 1998). Regarding infant performance, there is also no evidence that speech perception in infants varies as a function of hearing sensitivity in a population whose hearing abilities fall within normal limits.

Finally, one could assert that a unified 'language faculty' that varies genetically in the population (Fodor, 1983; Pinker, 1994) mediates the observed relationship. Epidemiological studies showing a genetically related factor in language disorders that results in language problems affecting multiple levels provide supportive data for the view that certain language abilities are genetically transmitted (Dale, Simonoff, Bishop, Eley, Oliver, Price, Purcell, Stevenson & Plomin, 1998; Flint, 1999; Lai, Fisher, Hurst, Vargha-Khadem & Monaco, 2001). If a global 'language faculty' is inherited, the clarity of mother's speech could be related to her infant's skills at phonetic discrimination. Both reflect the genetic link of a unified language capacity. However, there is little evidence to suggest that all components of language (e.g. as embodied in maternal speech clarity and infant speech perception) are inherited as a unitary factor varying in the population.

Despite the fact that genetic mediating factors, such as cognitive or sensory ability, or the inheritance of a general 'language faculty', cannot be ruled out, we favor the view that the clarity of mother's speech directly affects speech discrimination in the young child because infants are learning from language input. The current results are consistent with such a hypothesis.

Why should exaggerated acoustic-phonetic cues in infant-directed speech play a facilitating role in infants' speech perception development? Mothers' acoustic exaggerations in infant-directed speech, which make individual units more distinct, are likely to direct infants' attention to the appropriate acoustic information in speech, helping them learn the subtle dimensions that distinguish phonetic units in their native language. Evidence suggests that listening to a particular language early in life 'warps' perception, highlighting the critical acoustic differences between phonetic units of the language and reducing those that are irrelevant to native-language phonetic categories, a phenomenon observed in studies on infants from different cultures as early as 6 months of age (Kuhl *et al.*, 1992) and one that is apparent in cross-language studies of adults (Iverson, Kuhl, Akahane-Yamada, Diesch, Tohkura, Kettermann & Siebert, 2003). Maternal speech that exaggerates the relevant acoustic cues should facilitate the 'warping' process.

It is at this time in development, between 6 and 12 months of age, that infants become language-specific listeners. During this period, infants' performance on native-language phonetic contrasts significantly improves while their ability to discriminate foreign-language contrasts sharply declines (Werker & Tees, 1984; Kuhl *et al.*, 2001). At this age, phonetic learning is robust even for foreign-language material heard for the first time, suggesting that this is a particularly sensitive period for phonetic learning (Kuhl *et al.*, in press). Moreover, at this age, infants' phonetic skills and their abilities to detect phonotactic patterns in speech input are critical to the discovery of words, as shown in statistical learning tasks (Goodsitt *et al.*, 1993; Jusczyk *et al.*, 1993; Saffran *et al.*, 1996). Better phonetic abilities could thus promote word learning at a younger age. This reasoning is compatible with recent findings showing that higher levels of speech discrimination in individual infants early in life significantly predicts advanced later language skills (Benasich & Tallal, 2002; Molfese & Molfese, 1985; Molfese, 2000; Tsao *et al.*, 2003), suggesting that efficient phonetic processing early in the first year of life assists subsequent language development. The data provided here, demonstrating a relationship between maternal speech clarity and infant speech perception, allow one to advance the argument that during this early formative period of development, higher clarity in maternal speech assists infants in discovering the appropriate acoustic cues and developing neural networks that code this information.

It is of interest to assess the relationship between speech clarity and other quality-of-language measures as well as its potential long-term effects. Do mothers who

speak more clearly also use clearer grammar when addressing their infants? Do they speak more frequently to their infants, a factor shown to be related to children's lexical development (e.g. Hart & Risley, 1995; Hoff & Naigles, 2002; Huttenlocher *et al.*, 1991)? Studies have shown that ID speech is very effective in attracting infant attention (Cooper & Aslin, 1994; Fernald & Kuhl, 1987); does the quality of maternal speech input affect its attentional pull or the quality of mother–infant interactions? Are there long-term effects on infants? Although the majority of studies show that adults modify their speech when addressing infants across cultures, a few exceptions have been reported, such as the Kaluli in New Guinea (Schieffelin & Ochs, 1983). Does the course of speech perception development in infants raised in this culture differ from that of infants exposed to ID speech? Such questions, raised by the current findings, remain to be answered.

Compared to the poorly specified phonetic units in adult-directed speech (Klatt, 1986; Lindblom, 1963), the exaggerated acoustic characteristics of the phonetic units in speech addressed to infants may represent a general strategy to amplify the critical features of a specific language. Recent tests using computer models show that phonetic learning is enhanced when infant-directed, as opposed to adult-directed, speech is used, reinforcing the view the ID speech is a richer signal from which to learn (de Boer & Kuhl, in press). The relationship found in the current study between increased maternal speech clarity and increased infant speech perception performance suggests a much more important role for language input in child language acquisition than previously thought.

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