ABSTRACT

Title of Document: PATTERNS AND POSSIBLE INFLUENCES OF MATERNAL VOWEL CLARIFICATION ON CHILD LANGUAGE DEVELOPMENT

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There have been many studies examining the differences between infant-directed speech (IDS) and adult-directed speech (ADS). However, very few longitudinal studies exist that explore how patterns of maternal vowel articulation in IDS change as children get older, or whether these changes have any effect on a child's developing language skills. This study examines the vowel clarification of mothers' IDS at 10-11 months, 18 months, and 24 months, as compared to their vowel production in ADS. Relationships between vowel space, vowel duration, and vowel variability and child language outcomes at 2 years are also explored. Results show that vowel space and vowel duration tend to be greater in IDS than in ADS, and that a mother's vowel space at 18 months is significantly related to expressive and receptive child language outcomes at 2 years. Possible explanations are discussed.

PATTERNS AND POSSIBLE INFLUENCES OF MATERNAL VOWEL CLARIFICATION ON CHILD LANGUAGE DEVELOPMENT

By

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Introduction

Across various languages, researchers have found that people speak differently to infants than they do to adults. This distinct register is known as "motherese", baby talk, or infant-directed speech (IDS). A popular research question that has emerged from this finding is whether or not certain characteristics of IDS help to facilitate child language learning. Specifically, whether or not the acoustic properties of IDS play a crucial role in language development has yet to be determined.

Differences between ADS and IDS

There are certain attributes of infant-directed speech (IDS) that differentiate it from adult-directed speech (ADS). The most notable feature of IDS is its prosody, which is characterized by a higher fundamental frequency, wider pitch range, and slower overall rate of speech (Fernald & Simon, 1984). Mothers have also been noted to use more dramatic changes in pitch and loudness (Soderstrom, Blossom, Foygel & Morgan, 2008) and to prolong the duration of words (Bernstein Ratner, 1986) in order to emphasize clause boundaries, making individual syntactic units more obvious and recognizable. Changes in pitch and loudness also occur more often and with a more consistent pattern in IDS when new words are introduced (Fernald & Mazzie, 1991).

In addition to how it sounds, IDS is also structured differently than typical conversation among adults. Utterances directed towards infants tend to be shorter than utterances directed towards adults (Fernald & Simon, 1984), and generally incorporate less complex syntactic structures (Soderstrom et al., 2008). Studies have found that mothers modify their word order somewhat when introducing new vocabulary to their infants. To emphasize new words, they frequently place them at the ends of utterances in IDS, but not in ADS (Fernald & Mazzie, 1991; Aslin, Woodward, LaMendola, & Bever, 1996). The syntactic complexity of ADS is not the only factor that could make the signal more difficult to decipher. Some research has also found ADS to be severely under-articulated (Pollack & Pickett, 1964). Lindblom (1990) suggested that adults speak to other adults with more co-articulation and shorter phonetic segments because experienced listeners can easily predict the message even with a reduction of acoustic cues. Younger listeners, however, have had less exposure to speech and language. To compensate for this, it has been theorized that adults speak more clearly to infants, making phonetic segments longer and more distinct.

Several studies that compared the acoustic properties of IDS to those of ADS have found conclusive evidence of a clearer distinction between phonemes and greater consistency in how the same sounds are repeatedly pronounced in IDS (Bernstein Ratner, 1982; Bernstein Ratner, 1984; Kuhl et al., 1997; Cristia, 2010). Cristia (2010) explored phonetic differences between the sibilants /s/ and /ʃ/ in IDS and ADS and found that caregivers differentiate more clearly between consonant sounds to 12-14 month olds than they do to 4-6 month olds. Mothers have also been known to have a significantly greater voice-onset time (VOT) for initial voiceless stops in IDS compared to ADS when their infants are between the one and two-word stages of language production (Malsheen, 1980).

Researchers analyzing the acoustic characteristics of multiple different languages (e.g., English, Swedish, Russian, Mandarin) have come to similar conclusions when comparing vowel triangles from IDS and ADS (Liu, Tsao & Kuhl, 2009). In these studies, vowel triangles are formed by mapping out the formant values of the three "point" vowels (/i/, /ɑ/ and /u/) and measuring the area of the space that lies between them (a measure we might call "vowel space"). These vowel plots also provide a visual demonstration of how multiple productions of each target vowel cluster together, forming a region that researchers can use to determine the variability of the sample (a measure we might call variability of a given vowel formant characteristics). With a large enough vowel space, mothers can produce many different variations of each vowel sound while maintaining a clear distinction between different vowel categories, even if tokens within a region were somewhat variable in formant properties. Theoretically, this could translate to clearer and more intelligible speech, so many studies that investigate the acoustic characteristics of vowels in IDS have used vowel space and the amount of overlap that occurs between vowel categories as measures for overall clarity.

Research on vowel clarification to infants younger than six months has produced mixed results. A study in Norway examining IDS in six mothers of infants aged 0-6 months found their vowel space for vowels /i/, /ɑ/ and /u/ to be the same as or smaller than the vowel space of their speech to adults (Englund & Behne, 2006). However, in a similar study, Kuhl (1997) found mothers of 2-to-5-month-old infants to have larger, more "stretched out" vowel space in their IDS than their ADS. Unlike the

Norwegian findings, this analysis examined English-speaking mothers and recruited more participants (30 versus 6).

A clearer pattern emerged from a longitudinal study conducted by Bernstein Ratner (1984), which produced some of the only existing data on patterns of vowel clarification to children older than six months. Nine mothers and their infants were brought in for three visits: one at the child's pre-linguistic stage, another at the child's one-word stage, and the final one when the child had a mean length of utterance (MLU) of two or three words. The vowels /i/, /ɑ/ and /u/ (as well as other vowels) were gathered from naturalistic play sessions between the mother and her infant and then analyzed acoustically for formant values and duration. An additional ADS sample was obtained from an interview between the mother and an experimenter. Vowel plots were then constructed for the IDS and ADS formant values, which revealed similar vowel space and precision across listeners at the pre-lingual stage, but larger vowel space with fewer overlapping vowel categories in IDS to holophrastic (infants/toddlers at the one word stage) listeners. The most exaggerated vowel space occurred with oldest group of children who were combining words. A more recent study that used the same point vowels (/i/, /ɑ/ and /u/) found that mothers continue to clarify and elongate their vowels to children five years of age (Liu, Tsao & Kuhl, 2009).

Proposed influence of IDS

The fact that clear structural and acoustical differences between IDS and ADS have been established raises the question of whether the characteristics of IDS serve a functional purpose. Many researchers have agreed for some time that IDS is more successful in getting and maintaining the attention of infants in communication-based activities (Fernald, 1985; Cooper, Abraham, Berman & Staska, 1997), but some evidence has emerged to suggest that IDS actually benefits infants on a linguistic level. Singh and colleagues (2009) demonstrated support for the theory that IDS may actually help to facilitate language learning. In their study, thirty-two 7.5-month-old infants were tested using the headturn preference procedure. Infants were familiarized to one word in IDS and one word in ADS before they were presented with these words in a mix of IDS and ADS passages. On average, infants were found to listen longer to passages that contained words that were familiarized in IDS than words that were familiarized in ADS. These results show that infants appear to learn new words better in IDS than ADS.

MLU has been investigated as a potential factor in facilitating language learning, in part because it facilitates segmenting the acoustic signal in IDS. In a study of twenty-seven 45-minute play sessions between mothers and their infants, Bernstein Ratner (1996) found 56% of IDS utterances to be three words in length or shorter, which should theoretically make segmenting words from the running acoustic signal easier for infants. Roy (2009) later uncovered a distinct pattern in this behavior: caregivers decrease their MLU when they are attempting to teach an infant a new word and then increase their MLU again after the child has acquired it. This would explain why infants whose mothers shorten their MLUs as they are approaching one year of age have been shown to perform better on the *Receptive Expressive Emergent Language inventory (REEL)* when they are one-and-a-half years old than infants of mothers who do not (Murray, Johnson & Peters, 1990). A possible explanation for this is that reducing one's MLU limits the number of options for lexical segmentation, thereby helping infants identify individual lexical components within a sentence (Bernstein Ratner, 1996). This evidence further strengthens the hypothesis that certain features of IDS may impact infant language learning.

Possible influence of acoustic characteristics

The role that acoustic characteristics of IDS play in facilitating language learning is less widely studied, but it seems logical that clarity and consistency in the articulation of parental speech could enhance language acquisition in infancy. Thiessen, Hill & Saffran (2005) made an attempt to investigate how the acoustic cues in certain syllable combinations help infants to segment fluent speech into meaningful units. They created two versions of an artificial language; one set employed the prosodic characteristics of IDS and the other was spoken in an ADS register. Infants were presented with a continuous stream of syllables in which some syllables co-occurred more consistently than did other syllable combinations. This simulated a difference between syllables within a word (syllables that co-occurred) and syllables that crossed a word boundary. Infants were then tested on their ability to discriminate between syllable sequences that were words and those that were only part words. Results showed that infants were able to discriminate words from part words when exposed to IDS, but not after hearing ADS. This evidence indicates that the acoustic characteristics of IDS may actually help infants discover new word boundaries.

Another body of research that is beginning to address some of the same questions about IDS is the development of speech-recognition technology. Speech-recognition uses software algorithms to directly transcribe verbal input (Al-Aynati &

Chomeyko, 2003). While voice-recognition software is becoming more widely used in various work and commercial settings, it is far from perfect. A test of one commercially available speech-recognition software package revealed that it makes an average of 16.7 times the total number of recognition errors made by a human transcriber (Al-Aynati & Chorneyko, 2003). Some researchers in this field (e.g., Scharenborg, Wan & Moore, 2007) are eager to find out more about how acoustic features facilitate infant language acquisition so that they can create a more complete computational model that mimics the speech recognition process in humans. Rules for parsing the acoustic signal into individual, recognizable lexical items is the basis upon which speech-recognition programs are designed, so they must be able to recognize words from the acoustic signal in order to function (Scharenborg, 2007).

The research that has been done so far in the development of speech-recognition technology provides some insight into how acoustic characteristics of speech contribute to language learning. Currently, speech-recognition software is designed to learn as it is used and has been proven to respond better to more carefully articulated speech (Matheson, 2007). One study by Scharenborg, Wan & Moore (2007) uncovered additional evidence that certain speech-recognition programs experience confusion when vowels overlap. Overlapping vowel space frequently occurs in ADS, often due to vowel centralization towards the schwa vowel, but given a high level of expertise in a language and knowledge of the context of conversation, a listener can usually deduce what words are being said despite the presence of categorical overlap. Computer programs, like infants, are unable to bring real-world knowledge to the task. They do not have a sufficient lexicon to choose among likely targets. Therefore, these “listeners” may experience more difficulty processing speech when vowels become centralized and overlap in the same vowel space.

Kirchhoff and Schimmel (2005) took the next step to explore how speech-recognition programs might benefit from exposure to IDS as opposed to ADS. In their study, they trained a group of speech-recognition software programs with IDS and another group with ADS, then compared the programs’ performance with the register they were trained in to the one that they were not. This study differed from previous studies on IDS because, rather than selecting target words or utterances from the overall sample, this study included all content and function word tokens produced from IDS conversations. This provided a more realistic and comprehensive picture of the acoustic properties of IDS, and turned up surprising new results. It was found that ADS-trained speech recognizers presented with words in ADS were slightly more accurate than IDS-trained speech recognizers presented with words in IDS. However, when conditions were switched, the speech recognizers that were trained in IDS scored almost 10% higher on word recognition testing in ADS than the ADS-trained software did in IDS. In other words, the models that received training in IDS were more versatile and could adapt to different speakers better than ADS-trained models. Kirchhoff and Schimmel attribute this to the fact that their IDS speech samples were characterized by more overlap between vowel classes than ADS. They determined that being trained with more overlap would make it easier to later accommodate a speech pattern with less variability and more distinct classes.

Given the nature of the set of stimuli used in this study, the results may have been influenced by function words that make up the majority of everyday speech that infants are exposed to. Combining both content and function words may have compromised the overall clarity of the speech signal, which could have caused the ADS-trained group to out-perform the IDS-trained group under matched conditions. High variability combined with a small vowel space causes overlap among vowel categories, which can be confusing to a listener who does not yet have canonical representations of every phoneme. However, the IDS-trained group were higher overall achievers, which demonstrates that there may be pros and cons to being exposed to a largely variable speech signal in the early stages of language development.

Changes in IDS with infant age

There are various theories and increasing amounts of evidence that suggest that IDS undergoes structural changes as infants mature, in order to encourage further language development given their current level (Bernstein Ratner, 1982; Bernstein Ratner, 1984; Cross, 1977; Murray et al., 1990; Stern, Spieker, Barnett & MacKain, 1983). Adults tend to use fewer words, simpler sentences, and a more basic vocabulary with younger infants, introducing new words and syntactic structures as the infant demonstrates readiness to advance (Fernald & Simon, 1984; Soderstrom et al., 2008; Bernstein Ratner & Rooney, 2001). For example, when a child is in his/her late preverbal stage or early single word expressive stage, caregivers have been found to reduce their output to mostly single word utterances and lower their type-token ratios (TTRs) to a smaller set of words that typically have a high proportion of nouns. This provides the child with a learning platform from which it becomes easier for him/her to determine syntactic boundaries and expand his/her vocabulary. As the child acquires more language and becomes ready to learn new words, the caregivers will increase their TTR values and begin introducing more complex syntactic structures in multi-word utterances that often contain words used redundantly in the small set of multi-word utterances (Bernstein Ratner & Rooney, 2001). These findings correlate with the hypothesis that a mother will “fine-tune” her output to her infant based on her beliefs about the infant’s comprehension ability (Murray et al., 1990).

However, before a child can even determine what a word is, he or she must first be able to parse the acoustic-phonetic signal. Therefore, it is particularly relevant that changes in the acoustic characteristics of IDS have also been noted as infants become more competent in a language (Bernstein Ratner, 1982; Bernstein Ratner, 1984; Bernstein Ratner, 1996; Liu, Tsao & Kuhl et al., 2009). To date, the studies that have examined vowel clarity in IDS have not shown significant fine-tuning or language outcome results within infants’ first year of life, but there is evidence that this changes as the child’s verbal output increases. Bernstein Ratner (1984) found that a difference between vowel clarity in IDS and ADS became apparent once infants reached the one-word stage, and mothers clarified vowels even more when infants reached the 2-3 word stage.

In a longitudinal study of mothers and their children, Liu and colleagues (2009) found that there were differences across the board between vowel articulation in IDS at 1;0, IDS at 5;0, and ADS. Mothers were shown to exhibit a pattern of acoustic-phonetic exaggeration in all IDS samples when compared to ADS, but these modifications were more prominent in speech addressed to the preverbal infants than to the five-year-old children. This trend of vowel clarification they observed that increases as infants are just learning to talk and wanes as they become more competent language users suggests that a child's age and perceived language ability plays a large role in how adults speak to children.

Evidence for relationship between vowel clarity and infant language learning

The distinction between IDS and ADS has been likened to that between conversational speech and clear speech, a register commonly used in noisy environments or with hearing-impaired individuals to improve listener comprehension (Ferguson, 2002). Most of us have also had the inclination to use clear speech when talking to adults who are second language learners of English. This is because vowel intelligibility tends to be significantly higher in clear speech than in conversational speech (Ferguson, 2002). In a study comparing conversational speech to clear speech, Ferguson (2002) found vowel space expansion to be significantly greater and vowel durations to be significantly longer in clear speech, indicating that larger vowel space and elongated vowel durations correspond with increased vowel intelligibility. This implies that vowel articulation plays a distinct role in making an overall speech signal more accessible to listeners, and that speakers will implement these changes when they want to clarify their speech for "disadvantaged" listeners.

Adults have been found to be quite inaccurate in identifying nonsense sentences (e.g., "His quick world must pass in a flag") produced in a conversational manner, due to the fact that their prior knowledge and experience with speech and language could not have helped them predict such an odd group of words. However, when given nonsense sentences in clear speech, adults are able to identify them with an improved level of accuracy (Ferguson, 2002). Infants face this same disadvantage as they are learning language because they are unsure what to expect (Lindblom, 1990) given their limited lexical and syntactic hypotheses. However, they are up against a much more daunting task: learning how to successfully segment speech into smaller linguistic units while simultaneously trying to develop distinct phonemic representations (Roy & Pentland, 2002; Kuhl et al., 1997). Therefore, it makes sense that the children of caregivers whose IDS is characterized by clearly articulated vowels will have the upper hand in learning language.

Changes in vowel space have also been linked to infants' speech discrimination abilities. Liu, Tsao and Kuhl (2003) studied the speech discrimination abilities of 32 Taiwanese infants between six and twelve months of age to see if there were differences in how accurately they were able to discriminate between different words when exposed to IDS as opposed to ADS using head-turn preference testing. Results of the study showed that there was a significant exaggeration of vowel articulation in IDS when compared to ADS, and that there was a strong association between the size of mothers' vowel space and infants' performance on speech discrimination testing. The socioeconomic status (SES) of the infants' mothers (variables such as parental education, income level and occupation) had no impact on the results. All in all, the infants scored much higher on speech discrimination tasks when they listened to IDS, which suggests that the acoustic characteristics of IDS could encourage a faster process of child language acquisition. A similarly designed study by Song, Demuth and Morgan (2010) found that 19-month-old infants were approximately 500 ms faster to look at a target object when they listened to IDS that incorporated a vowel space area that was identical to that employed by Liu et al. (2003). Their response time increased (indicating slowed response time) when words were delivered in ADS. These studies conclude that vowel clarification in IDS helps to facilitate infants' word recognition.

All of this evidence suggests that a larger vowel space in IDS may potentially lead to better language outcomes in infants. However, the research to date that compares vowel clarity in IDS to language outcomes is extremely limited, so we can only speculate about the relationship that they share. This relationship may also be affected by other factors unrelated to IDS such as infants' innate abilities, the amount of exposure they have to language, their family structure, and SES. Nonetheless it will still be useful to determine if there is a relationship between acoustic properties of IDS and long-term language outcomes, potentially for the purpose of counseling parents whose children are at risk for or already diagnosed with a language disorder.

Present study

The present study followed infants and their caregivers from 10-11 months to 24 months to examine any changes that occurred in the acoustic characteristics of maternal IDS over time. Additionally, the correlation between the vowel clarity in maternal IDS at different chronological ages and the children's later language outcomes were explored. Vowel clarity to 10 and 11-month old infants, 18-month-old infants, and 24-month-old infants was determined by calculating the following measures:

1. The area of the vowel triangle created by the means of formants 1 and 2 for the "point vowels" (i.e., /i/, /ɑ/ and /u/[1]), to be called "vowel space" in further discussions. The vowel space area was calculated using the following formula devised by Liu et al. (2003) by using the following equation:

   Vowel space area = ABS {[F1i*(F2a – F2u) + F1a*(F2u – F2i) + F1u*(F2i – F2a)]/2}

   In this equation, 'ABS' is the absolute value, 'F1i' is the F1 value of the vowel /i/, 'F2a' refers to the F2 value of vowel /ɑ/, and so on.

2. The mean of the average durations for the three point vowels. We made the assumption that longer vowel duration assists the infant in mapping the vowel formant properties.

3. The mean of the variability measures of each of the point vowel categories. The variability measure for each of the point vowel categories was calculated by obtaining the standard deviations of F1 and F2 for each vowel category and inserting them into the following formula: pi*2sdF1*2sdF2. This resulted in the area of the ellipse that had been created by multiple productions of a target vowel, indicating the amount of variance that existed. Then, the values for all three point vowels were averaged together to create the measure referred to as "vowel variability".

[1] /ʊ/ was added because we anticipated that many of the participants would have a Mid-Atlantic dialect which is characterized by the frequent overlap of formant values for /i/ and /u/.

Language outcomes at 24 months included both expressive and receptive vocabulary standardized tests: the *Expressive One Word Vocabulary Test* (EOWVT) (Martin & Brownwell, 2010) and the *Peabody Picture Vocabulary Test* (PPVT) (Dunn & Dunn, 2007). Mothers included in the study also completed the *MacArthur Communicative Development Inventory* (MCDI) (Fenson, Dale, Reznick, Bates, Thal, Hartung & Reilly, 1993), an inventory of words that they believe their children have in their expressive vocabulary.

This study compared vowel clarity in four different conditions: IDS to 10 to 11-month-olds, IDS to 18-month-olds, IDS to 24-month-olds, and ADS to an unfamiliar adult. IDS at three distinct ages was chosen for analysis to see if there are any observable changes or trends that the mothers exhibit either individually or as a group throughout the early process of infant language learning. We also examined whether vowel clarity in IDS (as defined by the three exploratory measures) correlated with the children's language abilities at 2 years of age. This study provides a longitudinal analysis of the potential impact that vowel clarity may have on infant language learning across the first two years of life.

The first hypothesis of this study is that mothers will exhibit larger vowel space and elongated vowel durations when using IDS than when using ADS. We also added the feature of vowel variability, as an exploratory measure. As we will discuss, the variability with which point vowels are realized could potentially have both negative and positive impacts on the child's ease of speech recognition. Thus, in our analyses, the independent variable was listener age (10-to-11 months, 18 months, 24 months, adult) and the dependent variables were vowel space, vowel duration, and vowel variability.

The second hypothesis of this study is that vowel clarity will relate to the age of the child. Since mothers have been found to emphasize lexical and syntactic structures that their infants are ready to acquire, it is expected that vowels will become more clearly articulated in both content and function words over time as the infants begin to showcase their language abilities. This is what Bernstein Ratner reported in her 1984 study.

The third hypothesis of this study is that vowel clarity in IDS (as measured by vowel space, vowel variability, and mean vowel duration) will correlate positively with children's expressive and receptive vocabulary scores (i.e., standard scores on the *EOWVT* and raw scores on the *PPVT* and *MCDI*) at 24-months of age.

Methods

Participants

Participants were mother-infant dyads who were part of a larger longitudinal study at the University of Maryland. All mothers and their infants were native English-speakers, and all infants had been born within three weeks of their due dates and had not been previously diagnosed with developmental disorders or delays. Each dyad reported to the University of Maryland for visits when the child was 7, 10, 11, 18, and 24 months of age, but the data for the present study were only selected from their visits at 10-to-11-months, 18-months, and 24-months.

Initially, 35 mother-infant dyads had been chosen for this study because they had completed all of their visits and mother-child play sessions at 10 or 11, 18, and 24 months had been transcribed. Ten dyads were later excluded because they did not meet criterion for the minimum number of matched tokens (criterion explained on page 17), either because of a transcription error or distortions in the mothers' speech that made tokens acoustically un-analyzable. After the exclusions, there were 25 mother-infant dyads included in this study; 10 were used exclusively for content word analysis, 10 were used exclusively for function word analysis, and 5 exhibited enough content and function word tokens to be matched across groups.

IDS and ADS speech samples

Vowels used in acoustic analyses were extracted from audio-recordings of unstructured play sessions between mothers and infants and interviews between the mothers and an experimenter from the University of Maryland. Play sessions between mother-child dyads and adult interviews between the mother and an experimenter were recorded at 10-months, 11-months, 18-months, and 24-months. The 10-month and 11-month recordings were considered equal in terms child language stage, so target vowels from both ages were combined together for acoustic analysis. Tokens for each of the four target vowels (/i/, /ɑ/, /u/, /ʊ/) were first selected from the 11-month play sessions, and if there were not enough to meet criteria (i.e., less than 4), additional tokens were taken from a 10-month play session. All adult-addressed recordings were also considered equal.

Tokens were elicited in each of the play sessions by providing the mothers with toys whose names contained one of the target vowels. Experimenters instructed each mother to play with her child as she does at home for approximately 15 minutes, and did not reveal that maternal speech was one focus of the main study. Following the play session, a student research assistant interviewed each mother to obtain an ADS sample that contained the same tokens that were present in the mother's speech to her child. Mothers wore an Audio Technica Lavalier microphone during each interaction, and each speech sample was recorded as an uncompressed WAV file using a Marantz PMD660 Professional Portable Digital Recorder at a sampling rate of 44.1 kHz. Mothers were debriefed at study termination and offered the option to decline their IDS data for analysis. None chose to decline participation in this aspect of the study design.

Transcription methods

Each sound file was orthographically transcribed using the Computerized Language Analysis (CLAN) program developed by the CHILDES project (MacWhinney, 2009). This program allows for audio to be linked to every line of transcription, which makes it easier to locate and extract words for acoustic analysis.

Acoustic data selection procedure

This study was most concerned with the vowels /i/, /ɑ/, /u/, and /ʊ/. As noted earlier, although it is not a traditional point vowel, /ʊ/ was included because we had anticipated that many of the participants would have a Mid-Atlantic dialect, characterized by the frequent overlap of formant values for /i/ and /u/ (in other words, Baltimore area adults produce a rounded /i/ as in the French word "rue", rather than /u/). However, none of the participants appeared to have a significant overlap between those two point vowels, so the phoneme /ʊ/ was not used for further acoustic analyses.

After each participant's files had been transcribed, a frequency count of all of the words spoken by each mother was used (CLAN command FREQ (freq +t*MOT)) to identify potential target words in the transcripts that contain each of the point vowels. Words containing a target vowel that carried stress in the first syllable of the word were selected for content word analysis (e.g., *beaver, sushi, doctor*, etc.) and grouped by vowel category. In order to qualify as a participant in this study, a mother must have had at least four tokens in each vowel category, with the exception of /U/. Target words containing the vowel /U/ (e.g., *could, should, would*) were not collected in the function group due to their scarce presence in most child transcripts. An attempt was made to match tokens across addressee conditions within each participant according to phonetic environment; because the consonants surrounding a vowel have been shown to influence its formant frequency values (Stevens & House, 1963). We considered matched phonetic environments to be words in which the target vowel was surrounded by the same classes of phonemes. For example, "ball" could be matched with "doll," and "shoe" could be matched with "zoo." Word families (i.e., *cook, cooking, cookies*) were also used interchangeably. Each individual participant had a matched set of tokens that shared the same word root or amount of syllables within vowel categories that were used for acoustic analysis. However, we allowed for an uneven number of matched tokens within and across vowel categories, no less than four but no more than ten, in an effort to collect the maximum number of tokens for each vowel. The same principles of matching were applied to content as well as function words. The content words and the function words were plotted in separate vowel triangles to compare vowel space and vowel variability across each listener group. Tokens were separated by word class because function words tend to be characterized by shorter durations and reduced vowels (Bell, Breiner, Gregory, Girand & Jurafsky, 2009).

After tokens were selected, they were located in each of the participants transcripts using the CLAN command KWAL (kwal +t*MOT +s@targets.cut). Raw data were recorded in individual rows and columns containing the following information: phoneme of interest, transcript file containing the word, transcript line where the token was located, whether it was a content or function word, vowel duration, and frequency values of F1 and F2.

Acoustic analysis

The program Praat (Boersma & Weenink, 2009) was used to acoustically analyze each token. Once a token was located in CLAN, the utterance that contained it was exported directly to Praat. Using the spectrogram and auditory signal, the target word was isolated from the utterance and the vowel was isolated from the word. After visual inspection of the spectrogram, frequency values for the first and second formants (F1 and F2) for each target vowel were collected at the midpoint of the steady-state of the vowel. Praat was set to identify formants using a 50-ms Gaussian window over the range from 0 to 5500 Hz with a +6dB/octave pre-emphasis. If a vowel was located next to a glide or a liquid, formants were measured at the end of the midpoint of the steady state portion of the target vowel that was located farthest away from where formant met consonant. Rounded productions of /u/ that began as an /i/ and ended as a /u/ were measured at the end of the vowel when there was a steady state that was more typical of /u/ frequency values (the word *you* was always excluded because coarticulation made it likely that the /u/ would be realized as a rounded /i/). Tokens were excluded if the acoustic signal was disrupted or degraded by ambient noise or overlapping speech, if the vowel was too short to identify a steady state, or if clear formants were not present due to whispered speech or glottal fry. Praat was also used to measure the vowel durations of each token. Once a vowel was isolated from the token word that contained it, the duration was measured to the nearest thousandth of a second.

Praat was also used to plot the F1 and F2 values for each token and a Praat script was used to plot the area of the vowel triangle that resulted from mapping the full vowel space. This program calculated the variability for each vowel as well by obtaining the standard deviations of F1 and F2 for each vowel category and inserting them into the following formula: pi*2sdF1*2sdF2. The resulting measure represented the general spread of tokens within a particular vowel category. To get an overall measure of vowel variability, the measures for each vowel category were then averaged for each participant in each addressee condition.

Outcome measures

At each participant's 24-month visit, research assistants who were not involved in the previously described analyses administered the *EOWVT* and the *PPVT* according to the instructions provided in the test manuals. Additionally, each mother completed the *MCDI*, which provided an inventory of words that she believed her child had in his/her expressive vocabulary. Following each testing session, the *PPVT,* *EOWVT* and *MCDI* were scored individually by two different research assistants. If they did not arrive at the same score, the two scorers would meet to discuss the results and come to an agreement. Standard scores were used for the *EOWVT*, and raw scores were used for the *MCDI* as well as the *PPVT*, which is only normed on children older than 2 years and 6 months of age.

Statistical analyses

The first hypothesis of this study was that mothers would exhibit larger vowel space, elongated vowel durations, and increased vowel variability in IDS as opposed to ADS. To determine if these measures of vowel clarity correlated together in any addressee condition, we calculated Pearson's *r* among each measure of vowel clarity (the vowel triangle area, mean vowel durations, and vowel variability for F1 and F2 values) in each listener group. Analyses on content and function words were performed separately. Then, Kruskal-Wallis tests[2] were conducted for each of the vowel clarity measures across all listener and word class groups to determine if any differences existed between IDS and ADS or within different IDS conditions.

To determine if any measures of maternal vowel clarity can be useful predictors of child language outcomes, linear regressions were performed between all measurements of vowel clarity and raw scores on the EOWVT, PPVT and MCDI. A Bonferroni correction was used to reduce the risk of a Type I error. Paired t-tests were also used to compare children's outcome scores from mothers with the largest vowel space to those from mothers with the lowest vowel space. Again, content and function word analyses were performed separately.

[2] A Kruskal-Wallis was chosen over an ANOVA because not all groups were normally distributed.

Reliability

To determine inter-rater reliability for the acoustic analyses, a proportion of the tokens in were analyzed again by another research assistant. To accomplish this, every tenth token from each transcript utilized in the study was extracted into an Excel workbook for a second analysis. This resulted in a total of 360 (roughly 10.6%) of the tokens being measured twice. Reliability was calculated with Pearson correlation coefficients between each rater's values for F1, F2, and vowel duration. Results are displayed in Table 1. All measures were significantly correlated across raters, and substantial levels of inter-rater reliability were observed between measures of vowel duration and F1 values. The inter-rater reliability between measures of F2 values was lower, but still considered to be acceptable level (Multon, 2010).

Table 1: Reliability

	Vowel Duration	F1	F2
R value	.853	.85	.657
p value	<0.0001	<0.0001	<0.0001

Results

Vowel clarity summary data

Target vowels were divided into two main groups for all analyses, those in content words and those in function words. Content word vowels were analyzed in 4 conditions (IDS at 11 months, IDS at 18 months, IDS at 24 months, and ADS) and function word vowels were analyzed in 3 conditions (IDS at 11 months, IDS at 24 months, and ADS). IDS function words were not analyzed at 18 months due to the fact that only 5 mothers produced enough tokens to meet the criterion for analysis in the mother-child play sessions at that age. We analyzed 3393 tokens across all conditions with an average of 38 tokens per listener for content words and 25 tokens per condition for function words. Table 2 shows the summary of tokens that were included in the final analysis.

Table 2: Summary of tokens available for each vowel per condition for 25 mothers.

	Content Word Mean # of tokens	**Content Word Range of tokens**	**Function Word Mean # of tokens**	**Function Word Range of tokens**
/a/	9	5-10	8.5	4-10
/i/	9.6	5-10	9.4	4-10
/u/	9.3	4-10	7.4	4-10
Total	38	24-40	25	19-30

Initially, all statistical analyses were performed using averages for all mothers of each vowel clarity measure with each addressee. Mean values for vowel duration and vowel variability were calculated for each vowel and then averaged across point vowels. Descriptive statistics for vowel clarity measures are shown in Tables 3 and 4.

Table 3: Vowel clarity descriptive statistics for content words

	M	**SD**	**N**
11 months			
-Vowel space	926375.667	116646.911	14
-Vowel duration	.218	.052	14
-Vowel variability	217755.489	87198.818	14
18 months			
-Vowel space	911939.533	145430.909	14
-Vowel duration	.204	.047	14
-Vowel variability	226581.111	93504.305	14
24 months			
-Vowel space	895304.4	169384.821	14
-Vowel duration	.186	.05	14
-Vowel variability	183004.667	61491.686	14
Adult			
-Vowel space	675608.267	92540.355	14
-Vowel duration	.173	.027	14
-Vowel variability	166510.6	86142.218	14

Table 4: Vowel clarity descriptive statistics for function words

	M	SD	N
11 months			
-Vowel space	714056.8	208754.336	14
-Vowel duration	.121	.029	14
-Vowel variability	263685.667	58186.261	14
24 months			
-Vowel space	631118.07	94738.779	14
-Vowel duration	.106	.018	14
-Vowel variability	199221.8	54805.842	14
Adult			
-Vowel space	612642.133	174824.176	14
-Vowel duration	.118	.028	14
-Vowel variability	180155.244	82894.21	14

Comparison among vowel clarity measures

The next step in analyzing the data was to see if correlations existed among acoustical measures of vowel clarity. Pearson product-moment correlations were used to determine the level of relationship among measures of vowel space, vowel duration, and vowel variability, which were measured by calculating the standard deviations of the ellipses surrounding each vowel (see Tables 5 through 8). This analysis revealed a significant positive relationship between vowel space and vowel duration in content words addressed to 18-month-olds ($r(13)=.524$, $p<.05$); this means that as vowel length increased, vowel space became larger in IDS to 18 month old toddlers. However, this relationship was not observed in function words or in any other addressee condition. A significant negative relationship was observed between vowel duration and vowel variability in content words addressed to 24-month-olds ($r(13)=-.52$, $p<.05$) and in function words addressed to adults ($r(13)=-.653$, $p<.008$), meaning that as vowel duration increased, vowel variability decreased. Although correlations between duration and variability did not reach significance in any other conditions, there was a consistent negative trend throughout the data between duration and variability, which indicates that as duration increases, variability decreases across different listener conditions, possibly as a function of more time available to reach target vowel formants. There was no statistically significant relationship between vowel space and vowel variability at any age in either content or function words.

Table 5: Correlations [(r(p))] between different measures of vowel clarity to 10/11-month-olds

	Vowel Space	**Vowel Duration**	**Vowel Variability**
Vowel Space			
-Content Words	--	.395 (.145)	.025 (.929)
-Function Words	--	.429 (.111)	-.485 (.067)
Vowel Duration			
-Content Words	.395 (.145)	--	-.449 (.094)
-Function Words	.429 (.111)	--	-.066 (.815)
Vowel Variability			
-Content Words	.025 (.929)	-.449 (.094)	--
-Function Words	-.485 (.067)	-.066 (.815)	--

Table 6: Correlations [(r(p))] between different measures of vowel clarity to 18-month-olds

	Vowel Space	**Vowel Duration**	**Vowel Variability**
Vowel Space			
-Content Words	--	.524 (.045)*	-.096 (.734)
-Function Words	--	--	--
Vowel Duration			
-Content Words	.524 (.045)*	--	-.144 (.609)
-Function Words	--	--	--
Vowel Variability			
-Content Words	-.096 (.734)	-.144 (.609)	--
-Function Words	--	--	--

Table 7: Correlations [(r (p))] between different measures of vowel clarity to 24-month-olds

	Vowel Space	Vowel Duration	Vowel Variability
Vowel Space			
-Content Words	--	.001 (.998)	-.042 (.882)
-Function Words	--	-.178 (.525)	-.049 (.862)
Vowel Duration			
-Content Words	.001 (.998)	--	-.52 (.047)*
-Function Words	-.178 (.525)	--	-.088 (.755)
Vowel Variability			
-Content Words	-.042 (.882)	-.52 (.047)*	--
-Function Words	-.049 (.862)	-.088 (.755)	--

Table 8: Correlations [(r(p))] between different measures of vowel clarity to Adults

	Vowel Space	Vowel Duration	Vowel Variability
Vowel Space			
-Content Words	--	-.081 (.775)	-.03 (.916)
-Function Words	--	.264 (.341)	.122 (.665)
Vowel Duration			
-Content Words	-.081 (.775)	--	-.273 (.326)
-Function Words	.264 (.341)	--	-.653 (.008)**
Vowel Variability			
-Content Words	-.03 (.916)	-.273 (.326)	--
-Function Words	.122 (.665)	-.653 (.008)**	--

Note. **p*<.05, ***p*<.01. *N*=15 for the content and function groups

Comparison of vowel clarity measures in content words by addressee

After establishing relationships within groups of addressees, we used a Kruskal-Wallis test for each of the vowel clarity measures across all listener groups to identify how listener groups differed from one another in terms of the quality of vowels addressed to them. In a comparison of content words only, ADS was found to be characterized by a significant difference in vowel space compared to each individual IDS condition (F=11.7, p<.001). This finding supports a visual analysis of all of the vowel plots, in which 14 out of the 15 mothers in the content group demonstrated a smaller vowel space in the ADS condition compared to all of the IDS conditions (see Figure 1). We also found a significant difference in vowel duration between IDS at 11 months and ADS (F=2.84, p=.046) (Figure 2).

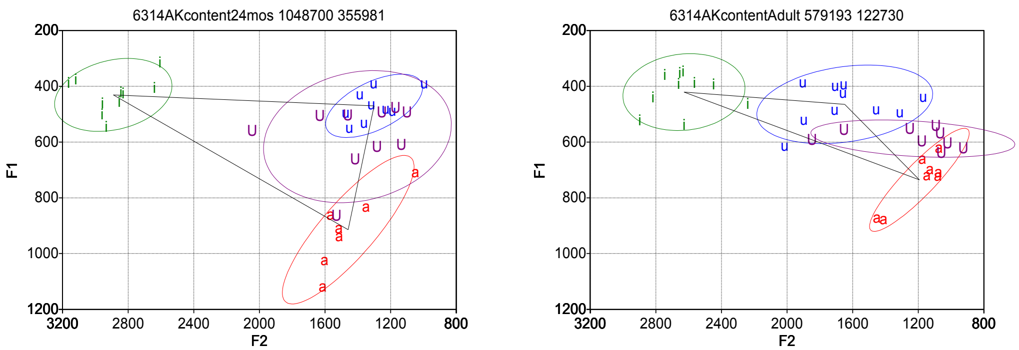


Figure 1: Example of a mother who exhibited reduced vowel space in ADS

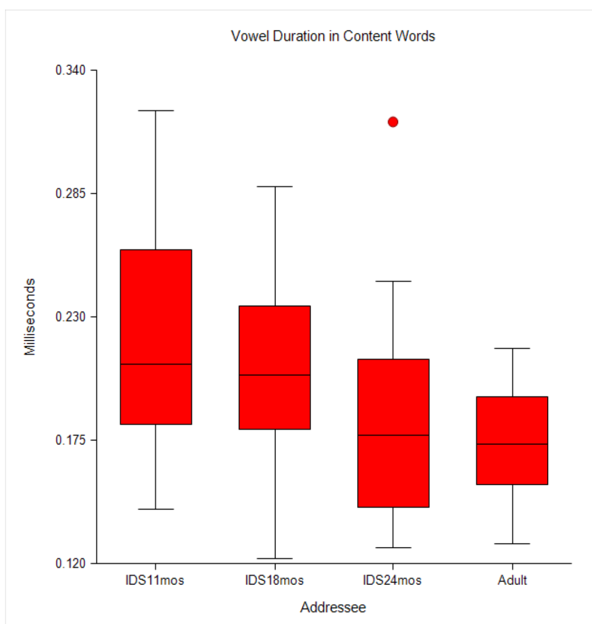


Figure 2: Differences in vowel duration by addressee in content words

There was, however, no main effect of addressee on vowel variability (F=1.76, p=.166). That is, in content words, the areas of the ellipses surrounding each vowel category did not differ significantly by addressee. Additionally, there were no significant differences found across IDS conditions for any hypothetical measure of vowel clarity (vowel space, duration, variability). In other words, there is a general pattern of vowel clarification in IDS when contrasted with ADS, but there does not appear to be one particular child age at which mothers exhibit a heightened level of vowel clarification in their speech that is significantly different from the signal they provide at other stages in their child's language development.

A visual inspection of vowel plots revealed a number of different trends, some linear and some non-linear, the most prominent one being the shrinkage of vowel space over time (see Figure 3). In other words, the older the listener, the more compressed the vowel space. A summary of these trends can be found in Table 9. Overlapping ellipses between point vowels were also noted in eight out of the 15 mothers' vowel plots; this occurred four times in IDS at 11 months, 3 times each in IDS at 18 and 24 months, and twice in ADS.

Table 9: Observed vowel space changes by addressee in content words

Pattern of Vowel Space	**# of Mothers**
IDS 11 > IDS 18 > IDS 24 > Adult	6 / 15
IDS 18 > IDS 11 > IDS 24 > Adult	3 / 15
IDS 18 > IDS 24 > IDS 11 > Adult	2 / 15
IDS 24 > IDS 18 > IDS 11 > Adult	1 / 15
IDS 24 > IDS 11 > IDS 18 > Adult	1 / 15
IDS 11 > IDS 24 > IDS 18 > Adult	1 / 15
IDS 11 and IDS 24 > Adult > IDS	1 / 15

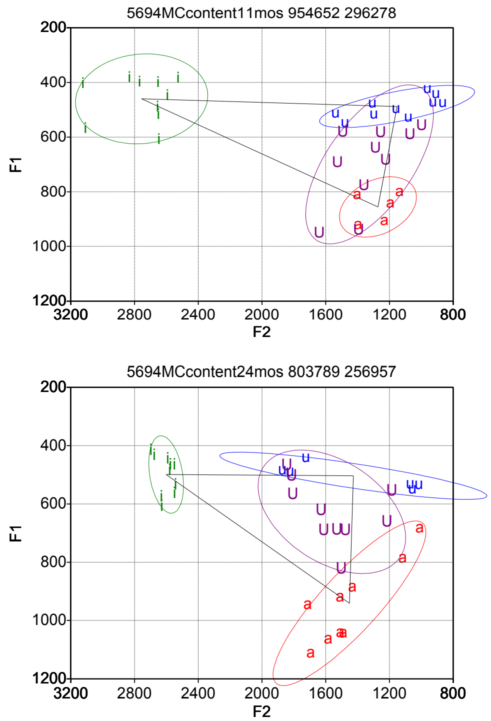


Figure 3: Example of a mother who reduces her vowel space as the age of the addressee increases

Comparison of vowel clarity measures in function words by addressee

Kruskal-Wallis tests were also conducted for each of the vowel clarity measures across all listeners for function words to see if the group differences observed for content words were seen in function word articulation. Results showed non-significant differences in vowel space ($F=1.58$, $p=.218$) and vowel duration ($F=1.38$, $p=.262$) among addressee conditions, but a significant difference in vowel variability at 11 months when compared to 24 months and ADS ($F=6.5$, $p=.003$). Figure 4 suggests a trend of greater variability within vowel categories in IDS to 11-month-olds, and smaller amounts in IDS to 24-month-olds and other adults.

These trends in variability are the inverse of those observed in the content word context. However, a visual inspection of vowel plots did reveal a similar trend for vowel space to decrease with listener age in seven out of the 15 mothers in function word articulation. Thirteen mothers also demonstrated some amount of overlap between vowel categories. Overlap was noted seven times in each IDS condition and nine times in ADS. Figure 5 illustrates a mother from the function word articulation analysis who demonstrates this pattern of shrinking vowel space in addition to the change in variability; both the vowel triangle and the ellipses surrounding each vowel appear to get smaller in each frame, as the child listener becomes older, and as the mother speaks to another adult. As this happens, the ellipses for point vowels /a/ and /u/ also begin to merge together. In other words, function words appear to be produced with more centralized vowels than content words.

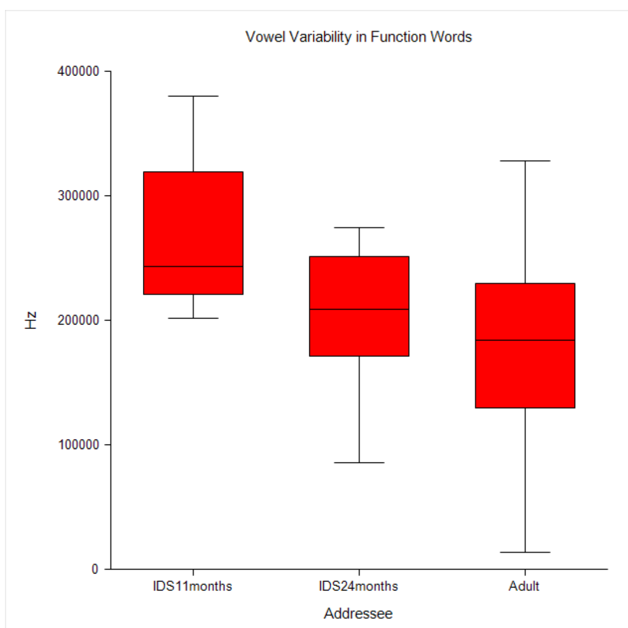
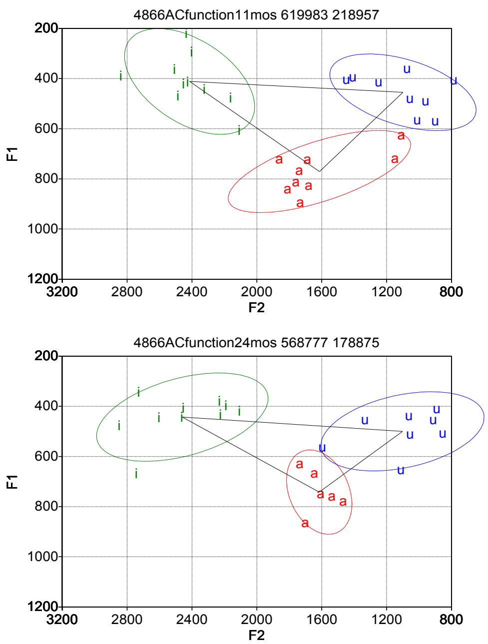


Figure 4: Differences in vowel variability by addressee in function words



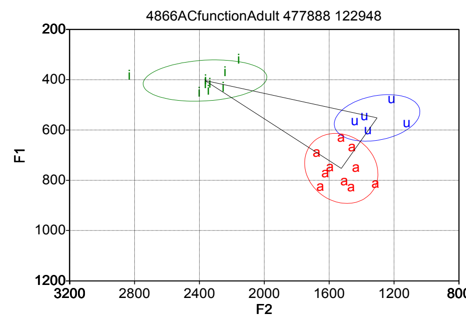


Figure 5: Example of a mother who reduces vowel space and vowel variability as the age of the addressee increases

Relationship between IDS vowel clarity and 24-month language outcomes

To determine if any measures of maternal vowel clarification were predictors of child language outcomes, linear regressions were performed between all content word acoustic features, and child outcomes. A Bonferroni correction was used to reduce the risk of a Type I error, which lowered the *a priori p* value to .002. At this alpha level, no relationships met criteria for significance at any age (see Tables 10 and 11). This was likely due to the small sample size that was used, since the actual *r* values were quite high.

The most obvious trend is that vowel space measures in both content and function words were positively correlated with child language outcomes in all IDS conditions. Although they did not meet criteria for significance, the vowel space that mothers displayed when producing content words to their children at 18 months words was strongly correlated with two standardized vocabulary outcomes (*EOWVT* r(14)=.557, p=.031; *PPVT* r(14)=.559, p=.03) and maternal function word articulation to their children at 24 months was characterized by a similarly strong correlation

(*EOWVT* r(14)=.571, p=.026; *PPVT* r(14)=.559, p=.022) (see Figure 6). Vowel articulation variability appeared to display the opposite relationship in content words, producing negative correlations across the board among IDS at 10/11 and 18 month and all language outcomes. In other words, the larger the variability in maternal vowel articulation in content words, the lower the child's scores were at 24 months on the three language outcome measures. No obvious trends were observed between vowel duration and any child language outcome measures.

Table 10: Content word linear regression [(r (p))] among vowel clarity measures and language outcomes

	EOWVT SS	**PPVT raw**	**MCDI raw**
Vowel Space			
-10/11 months	.493 (.062)	.322 (.241)	.096 (.733)
-18 months	.557 (.031)	.658 (.008)	.206 (.461)
-24 months	.414 (.124)	.536 (.04)	.089 (.753)
Vowel Duration			
-10/11 months	-.028 (.92)	.249 (.37)	-.006 (.99)
-18 months	.214 (.444)	.397 (.143)	.095 (.736)
-24 months	-.17 (.545)	.051 (.858)	-.126 (.655)
Vowel Variability			
-10/11 months	-.106 (.706)	-.368 (.177)	-.168 (.549)
-18 months	-.32 (.244)	-.268 (.334)	-.19 (.5)
-24 months	.091 (.75)	-.332 (.226)	.085 (.762)

Table 11: Function word linear regression [(r (p))] between vowel clarity measures and language outcomes

	EOWVT SS	**PPVT raw**	**MCDI raw**
Vowel Space			
-10/11 months	.435 (.105)	.147 (.59)	.125 (.658)
-24 months	.571 (.026)	.573 (.026)	.212 (.448)
Vowel Duration			
-10/11 months	.307 (.266)	-.251 (.366)	.206 (.461)
-24 months	.121 (.668)	-.1 (.724)	.102 (.718)
Vowel Variability			
-10/11 months	-.006 (.984)	.121 (.669)	-.009 (.976)
-24 months	.175 (.533)	.367 (.179)	.101 (.721)

No measures were significant at p<.002

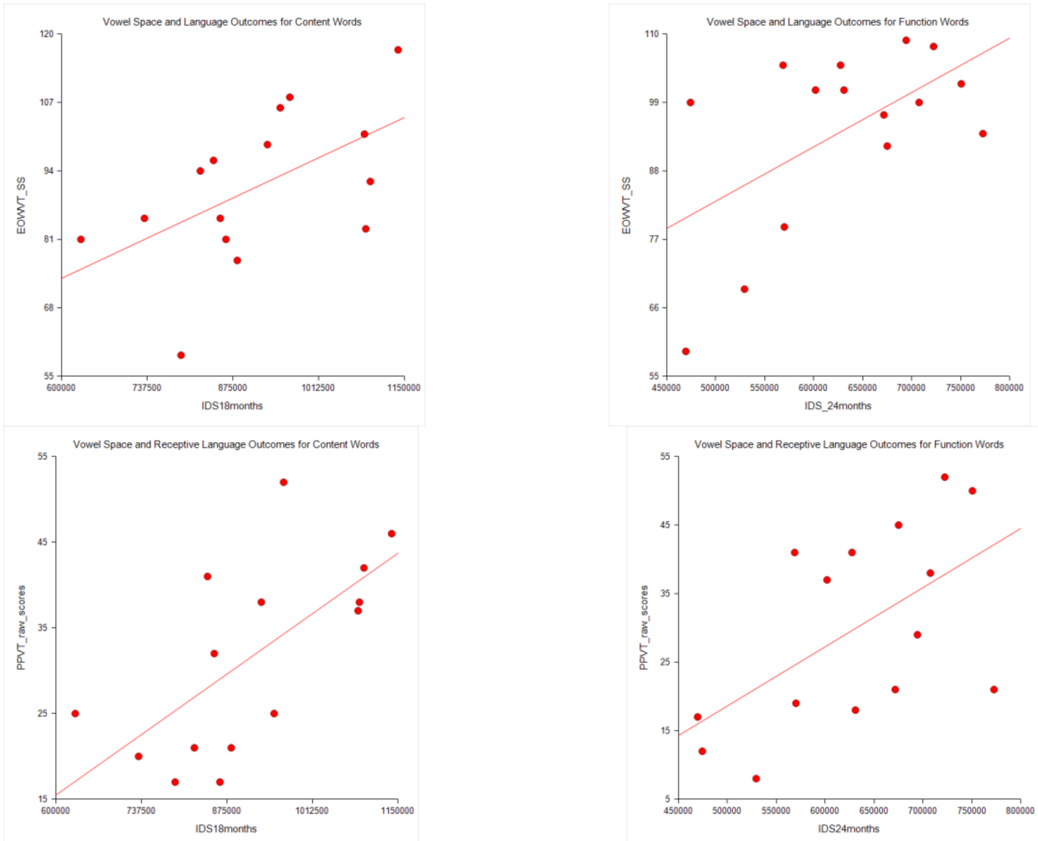


Figure 6: Plots of vowel space and language outcomes in content words (left) and function words (right)

Group comparison of 24-month language outcomes

In this analysis, mothers were divided into "max" and "min" vowel clarification groups and paired t-tests were completed in order to compare their children's language outcome scores. Mothers were ranked based on the area of their vowel triangles in each IDS condition; the participants with the seven highest vowel space measures were labeled as "max vowel space" mothers, while the participants with the seven lowest vowel space measures were labeled as "min vowel space" mothers. (The mother with the median vowel space was excluded from analysis). This process was repeated in each IDS condition, because some mothers exhibited an enlarged vowel space at one age and not others, which would cause them to change labels. Average group language outcome scores and t-test results are reported in Tables 12 and 13.

Table 12: Content word group comparisons

	Mothers with max vowel space		Mothers with min vowel space		
	M	**SD**	**M**	**SD**	**t scores**
24 month EOWVT mean Std. scores					
-10/11 months	98.9	11.246	85	14.754	t(13)=1.62, p=.131
-18 months	100.9	11.097	83	12.124	t(13)=2.079, p=.059
-24 months	96.6	13.049	84.6	15.23	t(13)=1.637, p=.128
24 month PPVT mean raw scores					
-10/11 months	35.1	10.351	29.3	12.406	t(13)= .763, p=.459
-18 months	106.1	8.42	92.4	8.883	t(13)=2.554, p=.024*
-24 months	102.9	12.799	93.3	7.323	t(13)=1.534, p=.149
24 month MCDI mean raw scores					
-10/11 months	341.1	155.669	304.6	152.576	t(13)= .336, p=.742
-18 months	418.6	137.753	227.1	89.109	t(13)=2.656, p=.02**
-24 months	370.6	175.37	298.1	144.238	t(13)=1.056, p=.312

Table 13: Function word group comparisons

	Mothers with max vowel space		Mothers with min vowel space		
	M	**SD**	**M**	**SD**	**t scores**
24 month EOWVT mean Std. scores					
-10/11 months	97.1	9.957	91.7	19.38	t(13)= .93, p=.371
-24 months	100.1	6.568	88.1	18.933	t(13)=1.322, p=.135
24 month PPVT mean raw scores					
-10/11 months	31	14.526	30.1	15.889	t(13)= .129, p=.899
-24 months	36.6	13.126	25	14.933	t(13)=1.464, p=.167
24 month MCDI mean raw scores					
-10/11 months	303.1	145.265	291.6	160.741	t(13)= .157, p=.878
-24 months	380.9	170.382	255.6	103.449	t(13)=1.288, p=.222

Note. * *p*<.05; ** p<.02,

Results show that the children who were exposed to a larger vowel space in their mothers' content word articulation at 18 months of age had receptive and expressive language outcomes (*PPVT* and *MCDI* scores) that were significantly higher than the scores of children whose mothers exhibited a smaller vowel space in child-directed speech. Although the rest of the differences did not achieve significance, the children who received relatively clarified speech input from their mothers consistently out-performed the group receiving less clarified speech on all three language assessment measures, in comparisons based on vowel space characteristics of both content and function word articulation characteristics.

We followed up these results with additional analyses to see if mothers with increased vowel space in general (regardless of addressee) had children with better language outcomes. To determine which mothers had the clearest overall articulation, vowel space was averaged across all IDS conditions for each mother, and they were divided into "max" and "min" groups once more based on the size of their overall vowel space. Mothers were also grouped into "max" and "min" groups based on how large their vowel space was in ADS. Both of these processes were completed separately for content and function words, and then t-tests were performed to compare the mean scores of children in each group. Results can be found in tables 14 through 17.

Table 14: Content word average IDS values and outcomes

	Mothers with max vowel space	**Mothers with min vowel space**	**t scores**
24 month EOWVT mean Std. scores	98.4	84.9	t(13)=2.329, p=.038*
24 month PPVT mean raw scores	35.7	29.3	t(13)=1.667, p=.121
24 month MCDI mean raw scores	392.1	313	t(13)=1.433, p=.178

Table 15: Function word average IDS values and outcomes

	Mothers with max vowel space	**Mothers with min vowel space**	**t scores**
24 month EOWVT mean Std. scores	99.7	91.7	t(13)=.99, p=.342
24 month PPVT mean raw scores	35	26.4	t(13)=1.044, p=.317
24 month MCDI mean raw scores	342	291.3	t(13)=.707, p=.493

Table 16: Content word average ADS values and outcomes

	Mothers with max vowel space	**Mothers with min vowel space**	**t scores**
24 month EOWVT mean Std. scores	97	85.7	t(13)=3.445, p=.005***
24 month PPVT mean raw scores	35.9	28.7	t(13)=1.268, p=.229
24 month MCDI mean raw scores	369.1	311.7	t(13)=.687, p=.505

Table 17: Function word average ADS values and outcomes

	Mothers with max vowel space	**Mothers with min vowel space**	**t scores**
24 month EOWVT mean Std. scores	95.3	92.4	t(13)=.299, p=.77
24 month PPVT mean raw scores	30.6	27.7	t(13)=.332, p=.746
24 month MCDI mean raw scores	325.9	293.9	t(13)=.282, p=.783

Note. * *p*<.05; ** p<.02, *** p<.005

Significant relationships were observed between child language outcomes on the *EOWVT* and mothers who had larger overall vowel space in content words. Non-significant differences but similar trends between groups were also seen in child scores at 24 months on the *MCDI* (Figure 8) and the *PPVT*. Augmenting the previous findings that suggested vowel space at 18 months had the largest impact on language outcome scores, these results imply that mothers who employ a larger vowel space regardless of their addressee have children with better expressive language skills ($t(13)=2.329$, $p=.038$). However, it is not clear whether these mothers are making conscious or unconscious modifications in their IDS, because a larger vowel space in ADS appears to be an even stronger predictor of child language outcomes than measures obtained from the same mothers' IDS ($t(13)=3.445$, $p=.005$). In short, it seems apparent that mothers who maximize their vowel space in content word articulation, regardless of register (IDS or ADS), have children with better expressive language skills at 2 years of age.

The function word analysis revealed no significant differences between any measures of language ability in children exposed to a larger vowel space and children exposed to a smaller vowel space. This may have been due to a more even distribution among mothers with larger and smaller overall vowel space, implying that they are not articulating function words as clearly as content words while their children are between the ages of 11 and 24 months (See figure 7).

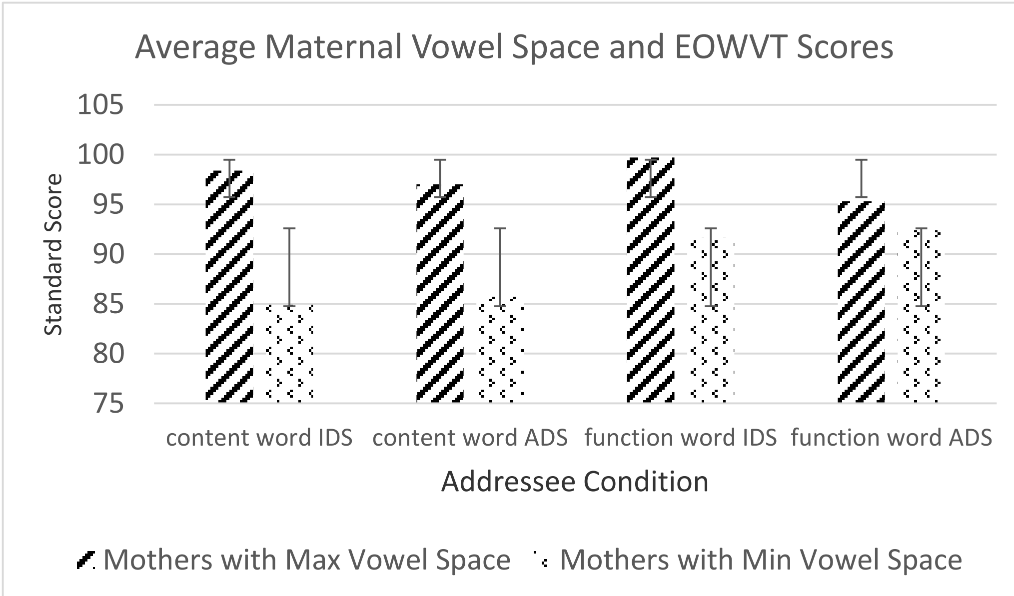


Figure 7: Group differences between EOWVT scores

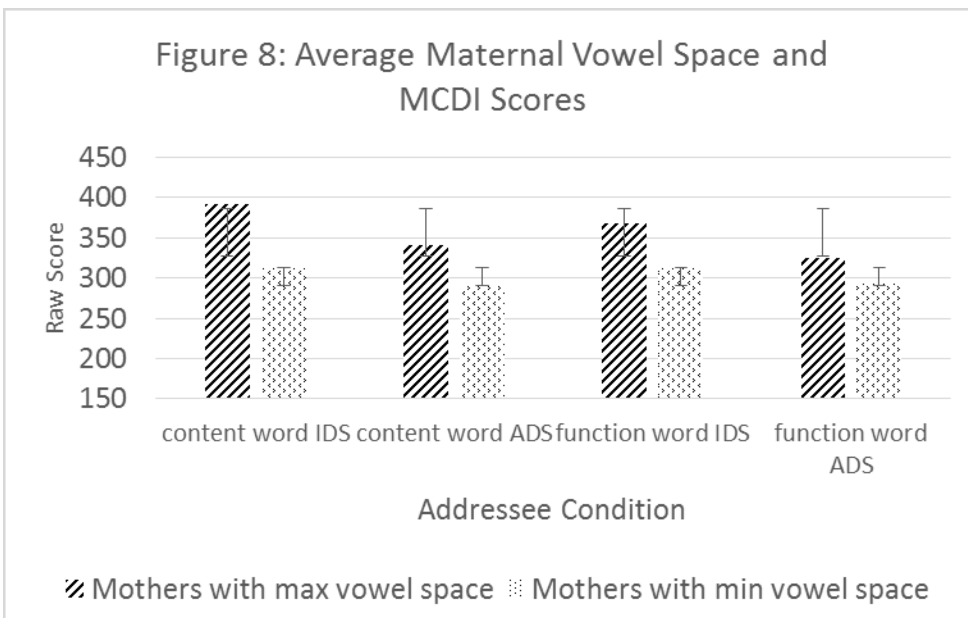


Figure 8: Group differences between MCDI scores

Discussion

The purpose of the present study was to identify and compare longitudinal patterns in maternal vowel clarification across three different measures of vowel clarity: vowel space, vowel duration, and vowel variability. More importantly, we also sought to determine whether any measures of maternal vowel clarity relate to expressive and receptive language outcomes at 24 months. Analyses of ADS and IDS at 10/11, 18, and 24 months yielded several significant findings that further inform previously gathered data on the subject of maternal speech clarity.

We predicted that mothers would exhibit larger vowel space, longer vowel durations, and increased vowel variability in IDS than in ADS. This hypothesis was generally supported, with the exception of a few observed differences when word class (content vs. function) was considered. In content words, measurements of vowel space and vowel duration followed the predicted trend; for function words, only vowel variability was observed to be significantly larger in IDS. While vowel space was actually found to be greater in IDS than ADS in both content and function words, this difference was only significant for content words. This indicates that, when compared to ADS, content words in IDS are characterized by vowel space expansion and longer vowel duration, whereas function words in IDS are actually characterized by *less* consistency (more variability) in how the same vowel is produced over the course of conversation addressed to the child. These findings are fairly similar to the trends reported by McColgan (2011), except that she reported increased vowel variability in IDS content *and* function words. This may have been due to the fact that her variability measurements included IDS at 7 months and 10/11 months, and she combined all IDS data together rather than conducting multiple analyses that highlighted differences between the two IDS conditions. Regardless, it is clear that the mothers in this study did appear to "clarify" their speech when addressing their language-learning children. However, the acoustical differences between content and function words in the IDS of the mothers in this study suggests that this pattern of vowel clarification may be limited to certain words that a mother appears to highlight, rather than her speech pattern as a whole.

Given past research on vowel articulation in IDS (e.g., Bernstein Ratner, 1982; Bernstein Ratner, 1984), we expected to see a trend of increasing vowel clarification across IDS conditions as the child grew older and developed more language skills, but the only measure of maternal vowel clarity that reflected a significant difference was variability. In function words, an inverse relationship was found between vowel variability and age of addressee, showing the most variability in IDS at 11 months, less variability in IDS at 24 months, and the smallest amount in ADS. Another non-significant trend reflecting change with age showed that, in approximately half of the participants, for both content and function words, the younger the listener, the larger the maternal vowel space.

These results are in partial agreement with Bernstein Ratner (1982, 1984), who found both content and function word vowel space expansion to children at her oldest stage (17-21 months); these children had MLU's between 2 and 3.5. However, she did not perform a statistical analysis, and used many more vowels than the point vowels selected here. Consistent with Bernstein Ratner (1982, 1984), we found content word vowel space expansion for children at the one word stage. A *post hoc* review of the language abilities of the 18-month-old children studied here showed that 11 of them had MLU's above 1.0.

Bernstein Ratner (1982, 1984) also studied only 3 children at each age, with a total of 5 eventually contributing mother-child interactions when the child was combining words during the longitudinal study. In contrast, we looked at 15 mother-child dyads who were fully matched across addressee conditions. However, our overall trend for vowel clarification in this study was for vowel space to diminish fairly linearly with child age for a large proportion of our study mothers (6/15), while Bernstein Ratner (1982, 1984) found the opposite trend.

One obvious difference in design is that we used child age to group addressees, rather than child linguistic ability. We do note that the 18-month group, for whom maternal vowel clarity (as defined by vowel space) differentiated outcomes at age 2, was itself fairly variable in terms of the children's language abilities. For instance, in the mother-child interactions at 18 months, number of words produced by the child ranged from 2 to 109, the number of word types ranged from 2-61, and MLU ranged from 1-1.435. Thus, an analysis that had grouped mother-child interactions by child language ability might have produced different findings.

To further investigate the relationship between maternal speech input and child language ability, measurements of vowel clarification were correlated with child language outcomes. No significant correlations emerged, although content word vowel variability in 10/11 and 18 month IDS appeared to correlate negatively with all language outcomes. This trend suggests that mothers who demonstrate higher levels of variability in their vowel productions tend to have children who do not perform as well on standardized language assessments at two years of age. One plausible explanation for this is that the mother does not expect the child to understand her if the child is at a lower level of language development, and therefore, either consciously or spontaneously, does not employ a register that enunciates vowels most clearly in her IDS. Another possible explanation is that high vowel variability could have a negative effect on a mother's overall intelligibility of speech; lower intelligibility levels might make it more difficult for a child to map new words and would in turn make language acquisition a slower process than it might be for a child who receives clearer speech input. For this reason, mothers were next grouped by the size of their vowel space alone in each IDS condition (e.g., those with largest and smallest vowel space profiles) and analyzed to determine whether dividing the sample into two dichotomous groups reveals any association with child language outcomes.

We hypothesized that mothers who articulated vowels most clearly in IDS conditions would have children who scored highest on measures of expressive and receptive language at 2 years of age (if clarity was defined as increased vowel space, duration and variability). Very evident differences emerged from this analysis. The children in the "max vowel space" group out-scored the "min vowel space" speech group on the *EOWVT*, the *PPVT*, and the *MCDI*, the differences between group language outcomes being most evident when the vowel space measurements were taken from IDS at 18 months. The analysis revealed a strong relationship between how clearly mothers differentiate between vowel sounds in IDS at 18 months and how strong their children's language skills were when measured six months later. Although we cannot infer the directionality of this relationship, whether it is the mother's speech or the child's present language ability that determines the relationship, prior findings that a larger vowel space corresponds with increased vowel intelligibility supports the notion that the maternal clarification in some way positively impacts the child's language development (Ferguson, 2002). It also makes theoretical "sense" that clarified speech would make it easier for a child to understand new words, recognize words used repetitively in conversation as instances of the same lexical type, and would in turn make language acquisition a faster process than it might be for a child who receives more acoustically degraded (centralized) or variable speech input.

Exploring vowel variability as a measure of vowel clarity

A standard definition of "vowel clarity" has yet to emerge, but it has been theorized that vowel clarity could be defined as a function of three factors: an enlarged vowel space, elongated vowel duration, and with an unknown contribution of vowel variability. These three measures did not intercorrelate significantly in any function word analyses, but in content words, we observed a significant positive correlation between vowel space and vowel duration and a significant negative correlation between vowel duration and vowel variability. These relationships were strongest at 18 months and 24 months respectively, although a non-significant negative correlation between vowel duration and vowel variability was present across all other child ages. Basically, these correlations indicate that mothers who exhibited a larger vowel space when their children were 18 months old tended to have longer vowel durations and less vowel variability. Conversely, mothers who exhibited a smaller vowel space had shorter vowel durations and more vowel variability. Since vowel space at 18 months was the only measure to correlate positively with child language outcomes, these results provide support that vowel space, vowel duration, and vowel variability trends could indeed be accurate indicators of vowel clarity.

One may question, however, whether or not vowel variability should be factored into a measurement of overall vowel clarity. It is possible that vowel variability only becomes a problem when it causes vowel categories to overlap (Kuhl, 1997). In the content word analysis, children who were exposed to increased vowel variability in IDS at 10/11 and 18 months were found to perform more poorly on language assessments, even though there was no statistically significant difference between vowel variability at 10/11 and 18 months and other addressee conditions. This may have been because, looking back at the visual analysis of overlap in the vowel plots, six out of the eight mothers who demonstrated overlapping vowel categories did so in their IDS at 10/11 or 18 months. Overlapping vowel categories should pose the real problem for children trying to map the phonemic representations of words in the input, and they do not always accompany an increase in vowel variability. Although vowel variability was found to be much greater in function word IDS, the majority of the overlap between vowel categories occurred in ADS. These examples challenge the assumption that increased vowel variability always contributes to poorer vowel clarity. Unfortunately, we do not know of any way to statistically compute the degree of vowel formant overlap; no prior research appears to have treated this problem computationally.

Few studies have analyzed trends of vowel variability across addressee conditions in IDS, so there are several conflicting theories about its effect on language learning. On the one hand, too much variability might impair a child's ability to recognize repeated variants of the same word as referring to the same lexical item. It has been shown that repetition aids tremendously in lexical development, but if the child cannot recognize that the same word is being repeated multiple times, they will not benefit from this. On the other hand, some researchers believe that increased variability should help child language-learning (Kirchhoff & Schimmel, 2005). It has been well established that before they can develop language, infants need to first learn how to process what they hear and hone their ability to map variations of the same sound into the same phonetic category. Thus, it seems possible that the child of a mother who exhibits a high degree of variability in her speech would have more highly developed auditory processing skills when tackling the task of assigning linguistic identity to conversational samples and could therefore be better equipped to process new words.

Limitations of the present study

The main limitations of this study lie in the number of spoken words that had to be excluded from acoustic analysis. An unfortunate negative consequence of analyzing naturalistic speech samples is the risk of not eliciting enough lexical tokens to match the same words spoken to different participants (listeners). There were not enough tokens in the mothers' speech samples to analyze function word IDS at 18 months, so longitudinal profiles in the mothers' pronunciation of both content and function words could not be observed. Additionally, there were 15 mothers who contributed usable tokens for content word analysis, and 15 who contributed tokens for function word analysis, but only 5 mothers produced enough matched tokens across the two IDS conditions and the ADS condition to provide data for all three groups. It is possible that other findings might have emerged if all of the participants had remained the same across all three conditions and group differences could be compared in all IDS conditions. It is possible that a larger participant pool might have resulted in clearer patterns and differences between word class and addressee conditions.

Profiles between groups may have also been influenced by the number of tokens that were analyzed for each phoneme in each addressee condition. Criteria for inclusion required that participants have at least 4 tokens in each condition. Thus, some group comparisons involved as few as 24 vowel productions. This limitation, in turn, reflected the large number of different lexical types produced during the mother-child and adult-adult conversations. In retrospect, more repeated tokens of the same word might have been available had the "props" (toys) available in the play sessions and subsequent interview been more constrained, forcing participants to refer to fewer objects and activities.

The limited number of matched tokens in this study could have also contributed to the lack of findings related to vowel duration. An emphasis was placed on matching target vowels according to phonetic environment, in order to obtain consistent and reliable formant frequency values. As a result, the selection of token words was not as constrained by characteristics that are known to affect the durational characteristics of vowels. For example, matching "bee" and "beet" was considered to be acceptable, since it is likely that the formant values for /i/ would be similarly affected in both contexts. However, the duration of /i/ could be considerably shorter in the word “beet,” since the vowel precedes a stop consonant. It is possible that selecting inequitable tokens that did not control for contexts that affect vowel duration may have obscured any potential relationship between vowel duration and child language outcomes.

Directions for future research

Results of the present study support the presence of a relationship between vowel clarity in IDS and child language outcomes. However, to confirm the results of the present study and to more clearly outline the longitudinal trends that occur across IDS conditions, more research is warranted. Future investigations of this topic should focus on the longitudinal differences between vowel clarity measures at different stages of child language development as opposed to chronological ages, grouping infants based on their expressive and receptive language abilities and/or mean length of utterance (MLU).

It would also be interesting to conduct an experimental research study that would investigate the effects that vowel clarification might have on word learning. Such an experiment could use a preferential looking task to assess how well infants are able to learn new vocabulary presented in IDS with maximal vowel space as compared to IDS characterized by more minimal vowel space. Results from such a study could indicate whether counseling mothers how to achieve a clearer speech register can be used as a method to facilitate language learning in at-risk populations.

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