ABSTRACT

Title of Document: THE RELATIONSHIP BETWEEN MATERNAL

SPEECH CLARITY AND INFANT LANGUAGE

OUTCOMES

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Mothers' use of infant-directed speech (IDS) may assist infants in decoding language input. IDS is characterized by exaggerated prosodic features (Fernald, 1989), shorter mean length of utterance (Cooper, 1997; Bernstein Ratner, 1996), repetition (Bernstein Ratner, 1996), and more highly clarified acoustic qualities (Bernstein Ratner, 1984; Malsheen, 1980) in comparison to speech directed to adults. However, it is not yet known to what extent such measures of maternal input have long-term impacts on language development. This thesis seeks to test the overarching hypothesis that children who receive more clarified speech input during the prelinguistic stage may be expected to have better language skills at an earlier age than children who receive poorer quality input.

THE RELATIONSHIP BETWEEN MATERNAL SPEECH CLARITY AND INFANT

LANGUAGE OUTCOMES

By

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Introduction

Mothers often use a special register when speaking to young children. This register is frequently referred to as infant-directed speech (IDS). Although unique characteristics of IDS have been identified in comparison to adult-directed speech, the impact of these characteristics on infant language development is less widely studied.

Characteristics of IDS

The prosody of IDS is arguably its most salient feature. Speech directed to infants typically has a higher average fundamental frequency and expanded pitch range compared to adult directed speech (ADS). These differences are true even in speech to newborns (Fernald & Simon, 1984). Mothers may also accentuate clause boundaries, using longer pauses (Fernald & Simon, 1984), changes in intensity and pitch (Soderstrom, Blossom, Foygel, & Morgan, 2008), and longer word durations (Bernstein Ratner, 1986), possibly assisting the infant in recognizing syntactic units. Speech rate is slower in IDS as well (Fernald & Simon, 1984).

Another important aspect of IDS is the structure and length of utterances. Utterances are generally shorter (Fernald & Simon, 1984) and less syntactically complex (Soderstrom, Blossom, Foygel & Morgan, 2008) in IDS compared to ADS. In fact, mean length of utterances to infants may be half as long as utterances directed to adults (Soderstrom et al., 2008). In addition to using shorter utterances, mothers may also assist children in learning vocabulary by positioning target words at the ends of clauses (Fernald & Mazzie, 1991; Aslin, Woodward, LaMendola & Bever, 1996). Repetition of words (Bernstein Ratner, 1996) and phrases (Fernald & Simon, 1984) is also common in IDS, as well as use of a core vocabulary in short carrier phrases (Bernstein Ratner & Rooney, 2001), qualities that may assist potential language learners. In fact,

computer simulations find IDS to be an easier language style through which to learn vocabulary (Roy & Pentland, 2002; Siskind, 1996).

Compared to speech addressed to adults, which is notoriously under-articulated (e.g., Pollack & Pickett, 1964), infant-directed speech has also been found to be more acoustically clarified. Voice onset time for voiced and voiceless consonants has been found to be more clearly differentiated in IDS compared to ADS (Malsheen, 1980). Better differentiation of sibilants has also been found in IDS compared to ADS (Cristia, 2010). In assessing vowels, overall speech clarity in IDS has been measured by examining the distinction between vowel phonemes using the vowel triangle created by the formant values for the "point vowels", /i/, /u/, /ɑ/. Vowel triangles have been found to be larger in IDS compared to ADS (Bernstein Ratner, 1984; Kuhl et al., 1997) resulting in patterns that should theoretically result in more distinct phoneme categories in input to infants. However, like many other attributes of IDS, including semantics and syntax, which are known to be "fine-tuned" to the child's perceived linguistic abilities (e.g., Snow, Perlmann & Nathan, 1987), this vowel clarification may depend to some extent on the age and language level of the child.

In an early study of vowel clarification in IDS, Bernstein Ratner (1984) analyzed vowels in nine mothers' IDS compared to ADS in a longitudinal study. IDS samples were collected during natural play interactions between mother-child dyads. Each mother's IDS sample was compared to an ADS sample collected through an interview with the mother regarding the play session. Vowels from words found in both IDS and ADS samples were acoustically analyzed for formant values and duration. Data were available from all 9 mothers to 4 groups of addressees: adults, pre-linguistic infants, infants at the one-word stage, and children with MLUs from 2-3. All children were over 9-months of age but entered the study at different ages. Three

participants' data were available for the pre-linguistic infant group, and 6 participants' data were

available for each of the other child ages. IDS directed toward the most advanced children

showed the least amount of overlap between the vowels. In other words, vowel categories were

more distinctly clarified in IDS addressed to this group compared to ADS or IDS to younger

infants. In addition, Bernstein Ratner found that clarification of function words increased

significantly when the children reached the 2- to 3-MLU level. These results indicate that

mothers not only clarify their speech to infants but that clarification patterns change depending

on the language level of the infants (Bernstein Ratner, 1984).

There is mixed evidence for vowel clarification to younger infants. In a study of English-,

Russian-, and Swedish-speaking mothers (n=10 per group), Kuhl and colleagues (1997)

compared the vowel triangle area for words directed to 2- to 5-month old infants and to adults,

and found evidence for clarification. They collected pre-selected target words from natural

speech samples, although the types of words or method of target selection was not explained.

Results showed that the vowel triangles were significantly larger in IDS compared to ADS in all

languages (Kuhl et al., 1997).

However, conflicting results were found in a different study of IDS to young infants.

Englund and Behne (2006) examined vowel duration and vowel space in IDS and ADS of 6

Norwegian mothers from naturalistic speech during home routines across infant ages 0-6 months.

They found that vowel space was smaller in IDS compared to ADS. All words containing the

point vowels (/i/, /u/, /ɑ/) were included in their analyses. In general, vowel duration was longer

in IDS compared to ADS across the ages. However, this study found vowel space to be

consistently smaller in IDS throughout the infants' first six months. These results were

inconsistent with their prediction that vowel space would be larger in IDS throughout the infants'

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first 6-months and contradicted the results of the studies mentioned previously. However, vowel space in Norwegian IDS had not been studied previously (Englund & Behne, 2006), so the results should be compared cautiously to studies of English IDS. Differing methodology in selecting target words for analysis, collecting the speech samples (e.g. semi-structured tasks versus natural speech samples), analyzing the vowels themselves, as well as different ages of infant addressees may also contribute to differing results.

Proposed influence of IDS

Infants have been found to show a preference for IDS over ADS (Fernald, 1985; Cooper, Abraham, Berman & Staska, 1997). During an operant auditory preference procedure, 4-month-old infants (n=48) turned significantly more often toward IDS than toward ADS (Fernald, 1985). Similarly, 23 4-month-old infants were found to have a longer mean looking time during maternal IDS compared to maternal ADS in a modified auditory preference procedure (Cooper et al., 1997). These studies compared IDS generally to ADS, and did not control for individual aspects of the IDS signal such as pitch, rate, speech clarity, or syntactic complexity. However, the results indicate that IDS attracts infants' attention, perhaps making it more salient as a vehicle for facilitated language learning. Recent research appears to support this proposed connection between IDS and language learning. Thirty-two 7.5-month-old infants were found to listen longer to passages containing words that were familiarized in IDS compared to those containing words familiarized in ADS, indicating that children learn words better in IDS than ADS (Singh, Nestor, Parikh & Yull, 2009).

The impact of individual characteristics of IDS on specific language learning and outcomes, such as vocabulary, articulation or syntax, is less widely studied. However, it has

been postulated that certain prosodic and acoustic characteristics of IDS, such as intonation contours (Fernald & Simon, 1984) and clause-final vowel duration (Bernstein Ratner, 1986), may assist children in learning syntactic structures. In a study by Kemler Nelson, Hirsh-Pasek, Jusczyk and Cassidy (1989), infants with a mean age of 8.5 months (range 7.0-9.6) were found to recognize appropriate clause boundaries in IDS but not in ADS during an auditory preference procedure. Thirty-two infants were split into two groups, an IDS and an ADS group. For each group, there were two versions of passages spoken by the same women to her infant or to an adult. In one version, pauses were placed at sentence and clause boundaries, while in the other version, pauses were placed within clauses. Infants were found to listen significantly longer to the passages with appropriate clause boundaries in IDS but did not show this preference in ADS. These results indicate that IDS may offer some benefits in helping infants segment clausal units, which may in turn assist in language learning (Kemler Nelson, Hirsh-Pasek, Jusczyk & Cassidy, 1989). Similar prosodic modifications may also aid in speech perception and learning lexical items (Fernald & Mazzie, 1991). Maternal language that follows the infants' current focus or joint attention has also been found to correlate with later measures of lexical development (Dunham & Dunham, 1992).

Additionally, aspects of IDS appear to change with the infants' age, and, therefore, may help facilitate language development in different ways (Cross, 1977). Pitch contours, pause duration, and amount of repetition have been shown to change across the infants' first 2 years (Stern, Spieker, Barnett & MacKain, 1983). The mean length of utterance (MLU) changes with infant age, becoming less complex closer to 1-year of age (Sherrod et al., 1977) and increasing as the child begins producing more language near 2-years of age (Stern, Spieker, Barnett & MacKain, 1983), indicating that mothers adjust their input based on the infants' stage of

language learning. Infants whose mothers decreased their MLU as the child approached one-year of age were found to have better receptive language scores on the Receptive Expressive Emergent Language inventory at age 1;6 (n=14) (Murray, Johnson & Peters, 1990). A more detailed level of this fine-tuning was observed in a longitudinal study by Roy (2009). He analyzed speech to one child from 9-24 months of age and examined adjustments in MLU in utterances containing different words around the time that the infant acquired that particular word. He found that caregivers' MLU decreased during the period prior to acquisition and then increased after acquisition of that word type (Roy, 2009). Therefore, it appears that adjustments in IDS may be made on both broad and detailed levels and that these adjustments may impact infant language abilities.

Acoustic Clarification Changes with Infant Age

Acoustic aspects of IDS also appear to change depending on the age and language ability of the addressee, indirectly supporting the theory that these qualities may play a role in teaching language (Bernstein Ratner, 1984; Liu, Tsao & Kuhl, 2009). For example, measures of vowel duration have been found to differ depending on the listener's age. Overall, vowel duration has been found to be longer in IDS than ADS (Bernstein Ratner & Luberoff, 1984). However, this finding was most significant in IDS addressed to prelinguistic infants near one year of age (Bernstein Ratner, 1986). Mothers may also use vowel lengthening to help signal clause boundaries (Bernstein Ratner, 1986). Bernstein Ratner (1986) found that mothers tended to lengthen clause-final vowels most to children who were on the verge of using spoken language but did not lengthen clause-final vowels as significantly to children who were already using expressive language.

Longitudinal examination of vowel clarification also supports the idea that speech clarity changes depending on the age of the listener. In a study of 17 Mandarin-Chinese speaking mothers, Liu, Tsao and Kuhl (2009) compared vowel space and duration in IDS to 7- to 10-month old infants and speech addressed to 5-year-old children. Vowel space expansion occurred in speech to the children at both ages to roughly the same degree. However, vowel duration was longer in IDS compared to child-directed speech. These results indicate that mothers adjust the acoustic qualities of their speech depending on the infant's age and language ability (Liu, Tsao & Kuhl, 2009) and imply that this aspect of IDS may support language learning at certain ages. However, more research is needed before the role of IDS in language development can be delineated.

Possible Influence of Acoustic Characteristics

It has been proposed that acoustic clarification in IDS may be influential in assisting infants in decoding and understanding the language input. Adult-directed speech is generally characterized by imprecise phoneme distinctions and fast rate without clear syntactic boundaries. Because phonemes are usually not clearly articulated in ADS, phoneme categories overlap and are, therefore, not usually well differentiated. A classic consequence is the difficulty of computerized speech recognition in handling signals from numerous speakers, or, more importantly, across a large lexicon (e.g. Al-Aynati & Chorneyko, 2003; Matheson, 2007; Scharenborg, 2007; Scharenborg, Wan & Moore, 2007). Speech recognition programs are similar to young infants in that they do not have the benefit of previous knowledge of the language and cannot easily use contextual cues to aid in comprehension of the acoustic signal. The perception of these programs is easier to test than that of infants and can potentially provide

insight into the difficulties that young language learners might face when presented with an acoustically messy signal like ADS.

Limited data exist on the direct relationship between acoustic clarification in IDS and infant language learning. However, given the generally messy acoustic signal in speech addressed to adults, it is unlikely that young infants would be able to easily extract and learn linguistic information from this signal. Theissen, Hill and Safran (2005) found that infants were able to distinguish real words from part words in IDS but not in ADS, indicating that infants are not able to successfully segment words in ADS compared to IDS. De Boer and Kuhl (2003) found that a computer program was better able to categorize vowels from IDS versus ADS due to the more distinct acoustic characteristics of the vowels in IDS. Computer speech recognition programs trained using IDS have been found to be better able to decode both IDS and ADS than programs originally trained using ADS (Kirchhoff & Schimmel, 2005). However, this outcome was explained to be the result of increased phonemic overlap which was found in the IDS sample compared to the ADS sample (Kirchhoff & Schimmel, 2005). Therefore, systems trained in speech with more overlapping phonemic categories (i.e. IDS) were more easily able to decode speech with less overlap (i.e. ADS) (Kirchhoff & Schimmel, 2005). On the other hand, those systems trained to expect little overlap (i.e. those trained on ADS) had significantly more difficulty decoding IDS, which had more phonemic overlap than the ADS (Kirchhoff & Schimmel, 2005). Kirchhoff and Schimmel hypothesized that this contradictory increase in overlap in IDS was possibly because mothers under-articulated common, predictable words while over-articulating novel words as a teaching technique. Despite the differing characteristics of IDS, these studies seem to support the idea that infants as well as computers are more successful in extracting acoustic information from IDS compared to ADS.

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Evidence for Relationship between Acoustic Clarification of Vowels and Infant Language Learning

There is mounting evidence that acoustic qualities of IDS are different from those of ADS. However, there is limited research examining the direct connection between the specific qualities of maternal speech input and children's language abilities. Liu, Kuhl, and Tsao (2003) studied the correlation between vowel space in IDS and infant's speech perception abilities. Sixteen 6- to 8-month old infants and sixteen 10- to 12-month old infants and their mothers were included in this study. They found a strong correlation between the vowel triangle area in IDS and infants' speech discrimination abilities. A recent study by Song, Demuth and Morgan (2010) examined the effect of vowel clarification on word recognition in 48 19-month-old infants. They found that infants identified target words more quickly during a preferential looking procedure when the stimuli contained hyper-articulated vowels compared to IDS stimuli that were modified to contain hypo-articulated vowels. Therefore, the vowel clarification found in IDS appears to play an important role in infants' ability to recognize words (Song et al, 2010). Given the link between maternal speech clarity and infant perception and between infant perception abilities and later language outcomes (e.g. Newman, Bernstein Ratner, Jusczyk, Jusczyk & Dow, 2006), it is possible that maternal speech clarity may also relate to later language outcomes. Currently, only a limited number of studies have examined this potential link.

Song (2009) examined the correlation between maternal vowel clarification and the children's later vocabulary size. She analyzed vowels in 3 words (i.e. *boxes, sheep, shoes*) in the utterance-final position from semi-structured language samples to 30 17-month-old children. Vowel space was measured using the formula that Liu, Kuhl and Tsao (2003) also used to

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calculate the area of the triangle from the midpoints of /i/, /a/, and /u/. Song found that vowel

space to 17-month-old children was only slightly larger than the AD vowel space calculated by

Kuhl et al. (1997) and smaller than the ID vowel space to 2- to 5-month old infants in Kuhl et al.

(1997). However, she noted variability among mothers and a correlation between vowel

duration and vowel space in her sample.

In her longitudinal analysis, Song (2009) examined the correlation between vowel space

to 17-month olds and vocabulary size at 19- and 25-months of age as measured by the

MacArthur Communicative Development Inventory (MCDI). No significant correlation was

found between vowel space and vocabulary size at either age. However, it is possible that

speech clarification may not be as significant or influential to children at the age examined in this

study because they have already begun to use expressive language. Significant correlations may

be more likely when speech clarification to prelinguistic children closer to 1 year of age is

measured.

In addition to acoustic qualities of maternal input, Song (2009) also examined the

relationship between quantity of maternal language input and children's vocabulary outcomes.

In the same sample of participants, Song found that the number of tokens and the number of

types used by the mothers at 17-months of age correlated significantly with children's

vocabulary scores at 19-months of age but not at 25-months of age. Song (2009) hypothesized

that these results might be because additional sources of language input may come into play as

the children get older, so maternal input has less of an effect on outcomes at the older age. No

significant correlations were found between maternal TTR and maternal MLU and children's

vocabulary scores at either age tested. In a different study by Rowe (2008), children (n=45)

whose mothers use better quality (i.e. higher vocabulary diversity and MLU, and fewer directive

statements) and higher quantity of language input at age 30 months were found to have better scores on the Peabody Picture Vocabulary Test at age 42 months (Rowe, 2008).

Song's (2009) study is currently the only longitudinal study examining the effects of maternal speech clarity on prelinguistic infants' later language outcomes. Given the potential relationship between infant-directed speech clarity on language outcomes, further research in this area is warranted. If a correlation does exist between these variables, this knowledge may be useful in counseling parents, particularly those of infants already at risk for language difficulty. However, it is important to note that IDS is only one of several factors that may impact infant language learning and outcomes. Infants' innate abilities, family structure, socioeconomic status, interaction with other adults and children are just a few examples of additional factors that may relate to later language abilities. In addition, IDS is not necessarily used in all cultures, and children raised in these other cultures learn language just as well without the maternal use of IDS. The current study examines the potential link between particular aspects of maternal speech input and longitudinal language outcomes in a relatively large sample of children. Although this study will focus on the impact of acoustic characteristics of IDS and quantity of IDS, one cannot discount the influence of several additional factors on language development. Given the fact that maternal IDS is not the only source of input to children during their early years, this study will also provide some insight into whether maternal IDS actually has an effect on long-term language outcomes.

Present Study

The present study examined the correlation between the extent of vowel clarity and quantity of language in maternal IDS to prelinguistic infants and the children's later language

outcomes. Vowel clarity to 9.5- to 12-month-old infants was determined by calculating three

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/)

2. The mean of the average durations for the three point vowels.

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 using the

formula, pi*sqrt(det(cov))/2. This formula calculates the area of the ellipse created from

the covariance matrix of F1 and F2 for each vowel category. The average of these values

for the three point vowels was calculated to create the measure that we will call "vowel

variability".

Quantity of language was defined as the average number of real word tokens and real word types

spoken per minute during an 8-20 minute play session. 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). Additionally, mothers completed the *MacArthur*

Communicative Development Inventory (MCDI) (Fenson, Dale, Reznick, Bates, Thal, Hartung &

Reilly, 1993), an inventory of expressive vocabulary. Speech articulation outcomes will be

measured using the *Goldman Fristoe Test of Articulation* (GFTA) (Goldman & Fristoe, 2000).

Speech samples from 25 mothers were collected and analyzed. This study compared

vowel clarity in two conditions from each mother, IDS to preverbal infants and ADS to an

unfamiliar adult. IDS to 9.5- to 12-month-olds was chosen for analysis because the infants are at

the cusp of language production at this age, and mothers may be most likely to fine-tune their speech clarity to this level of development. We also examined whether vowel clarification in IDS correlated with the children's language abilities at 2-years of age. This study allowed for longitudinal analysis of the relationship between speech clarity to young language learners and later language abilities.

The first hypothesis of this study is that mothers will show greater vowel clarity in the IDS condition compared to ADS. The independent variable was listener (infant versus adult) and the dependent variables will be vowel space, vowel duration and vowel variability. Three paired t-tests were used to compare the area of the vowel triangle comprised of matched words containing the "point vowels" (/i/, /u/, /ɑ/) in IDS versus ADS, to compare mean vowel duration in both conditions and to compare vowel variability in both conditions. We expect vowel space and duration to be larger in IDS. Because vowel variability is likely to increase as mothers highlight differences among words by expanding their vowel space and vowel durations, we expect variability to be larger in IDS compared to ADS.

The second hypothesis of this study is that vowel clarification (i.e. the area of the IDS vowel triangle areas, the mean vowel duration in IDS and mean vowel variability) will correlate with children's receptive vocabulary (i.e. raw score on the PPVT) at 24-months of age.

Additionally, we predicted that vowel clarification will correlate with children's expressive vocabulary scores on the EOWVT or MCDI at 24-months of age.

We also examined whether vowel clarification in IDS correlates with articulation test scores on the GFTA, a relationship that has not been examined extensively in previous research.

Because we are considering vowel clarification to be a proxy for overall speech clarity, we hypothesize that mothers who produce clearer speech may have children with better articulation.

Further, we hypothesized that quantity of language (i.e. frequency of real word tokens and types per minute) will correlate with children's receptive and expressive vocabulary scores at 24-months of age.

Methods

Participants

Participants were 25 mother-infant dyads (8 females, 17 males) who were part of a larger longitudinal study at the University of Maryland. Infants were born within 3 weeks of due date and were learning English as their native language from native English-speaking mothers. Infants included in this study did not have previously-diagnosed developmental problems. Data to be analyzed were collected when the infants were between 9.5 and 12 months old. Outcome data were collected when the children were 24 months old. Four mothers were excluded from analysis because they did not have enough analyzable vowel tokens in their samples. Therefore, only 21 mothers were included in the final analysis.

Eleven of the 21 children were first-born or the only child in the family at 24 months. All of the 21 mothers had at least a college degree, and 14 of them had a graduate degree. Mothers were asked to identify the primary caregiver for their children at the 24 month visit. We did not collect this information during the younger visits. Many of the mothers (8/21) indicated that they were the only caregiver for their child during the work week. Seven additional mothers identified themselves as the primary caregiver but that a daycare, nanny or grandparent provided care during some portion of the week. The remaining 6 mothers reported that children were in

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daycare or with a nanny or grandparent for the majority of the week. All families spoke English as the primary language with a limited number of families reporting exposure to additional languages less than 10% of the time at the 24 month visit.

IDS and ADS Speech Samples

We collected audio-recordings of unstructured play sessions between mothers and infants and of interviews between the mothers and an experimenter at the University of Maryland. Mother-child dyads were recorded during play sessions twice between ages 9.5- and 12-months. The play session recorded second was analyzed first for each dyad, and if these sessions did not provide enough analyzable tokens for acoustic analysis, tokens from the earlier session were also included in the acoustic analysis. Mother-child dyads were provided with toys whose names contain one of four vowels (/i/, /ɑ/, /u/, /ʊ/). Mothers were instructed to play with their infants as they would at home and were not aware that their own speech was the primary focus of the session. The play sessions lasted approximately 15 minutes and were followed by an interview between the mother and a student research assistant who was not involved in later data analysis. The purpose of the interviews was to collect adult-directed speech samples with target words that could be directly compared to the infant-directed samples. Mothers wore an Audio Technica lavalier microphone on their clothing throughout both interactions, and the speech samples were recorded as uncompressed WAV files using a Marantz PMD660 Professional Portable Digital Recorder at a sampling rate of 44.1 kHz.

Transcription Methods

The WAV files were uploaded to a computer. Each file contained both the mother-child play session and the interview with the student clinician. The files were split into two files using

Audacity (http://audacity.sourceforge.net/). One file contained only the IDS sample (i.e. the mother-infant play session) and one contained only the ADS sample (i.e. the interview). Each sound file was orthographically transcribed by research assistants using the Computerized Language Analysis (CLAN) program developed by the CHILDES project (MacWhinney, 2009). CLAN allows for a direct link between the sound file and the transcript using smaller segments called "bullets", which allow for more accurate transcription.

Acoustic Data Selection Procedure

Following transcription, a frequency count of all of the words spoken by the mothers in each transcript (IDS and ADS) was collected using the CLAN command FREQ (freq +t*MOT) in order to identify words for further analysis. Words in the IDS sample containing one of four vowels (/i/, /u/, /ɑ/, /ʊ/) were selected. The vowel /ʊ/ was initially included because formant values of /i/ and /u/ frequently overlap in the Mid-Atlantic dialect, which is the dialect that the majority of participants spoke. However, following visual inspection of the vowel triangle plots, we determined that none of the mothers had significant overlap between /i/ and /u/ to indicate a dialectal difference. Therefore, we used the traditional "point vowels" (/i/, /u/, /a/) to create the vowel triangle. The phoneme /ʊ/ was not used to calculate vowel space, vowel durations or vowel variability for further analyses.

Only those words that were also present in an ADS sample were included for analysis, and the same number of each token were included in each condition for each participant. Because the frequency of occurrence of each vowel varies in conversational English (Mines, Hanson & Should, 1978), we allowed an uneven number of matched tokens for each vowel

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category. All matched tokens for each vowel category were plotted to maximize on the number of tokens analyzed and to more closely represent the distribution of phoneme occurrence in naturalistic language samples. Both content and function words were included for analysis.

After selecting tokens for analysis in each FREQ list, a text file containing all of the selected tokens was created. The CLAN command KWAL (kwal +t*MOT +s@targets.txt) was used to locate the tokens within each transcript. Excel workbooks were created for each mother containing a spreadsheet with infant-directed tokens and another spreadsheet containing matched tokens from ADS. Each token was listed on individual rows in the spreadsheet along with the following data: phoneme of interest, transcript file containing the word, transcript line where token is located, whether it is a content or function word, vowel duration, and frequency values of F1, F2, F3.

Acoustic Analysis

Each token was acoustically analyzed using Praat (Boersma & Weenink, 2009). Bullets containing each token were exported directly to Praat from CLAN. The target word was isolated from the audio segment in Praat by research assistants using the spectrogram and acoustic signal. Formants were calculated over a 50-ms Gaussian window with 25% overlap, evaluating the range from 50 to 5500 Hz with pre-emphasis of +6dB/octave.   Frequency values for formants 1, 2, and 3 (F1, F2, F3) for the target vowel were collected at the midpoint of the steady-state of the vowel (See Figure 1), which was determined through visual inspection of the spectrogram by the research assistants. If ambiguous formant values were provided by Praat, the values that most closely matched the perceptual characteristics of the vowel were selected by the research assistants. For example, if the acoustic signal was perceived as an /i/ but Praat provided an F2

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value consistent with an /u/ phoneme, that value was ignored and the next highest formant value was recorded as being F2 (See Figure 2). If a vowel was diphthongized, formants were measured at the midpoint of the steady state of the target vowel. Tokens were excluded if ambient noise or overlapping speech degraded the acoustic signal, if no steady-state could be identified (e.g. short duration, proximity to a glide or liquid), or if clear formants were not present due to whispered speech or glottal fry.
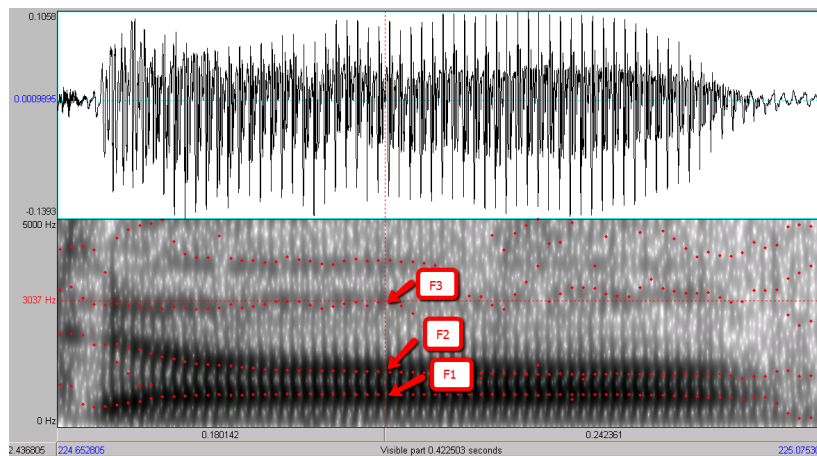

Figure 1: Spectrogram of "Doll" with formants measured at the midpoint of the steady state.
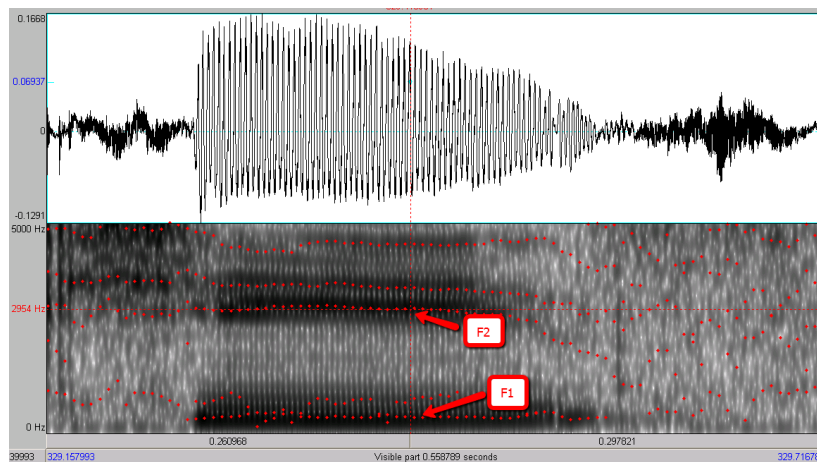

Figure 2: Spectrogram of "keys". Extraneous second formant is displayed around 500Hz. F2 was measured closer to 3000Hz and closer to F3, which is the expected value for F2 for /i/.

Formant values were converted from Hertz to Bark values in order to normalize the values across speakers. We used the convert.bark program from the Vowels package in the R Software Environment. This program uses the formula by Traunmuller (1997): $Z_i = 26.81/(1+1960/F_i) - 0.53$.

Formant values in Bark units were plotted to create vowel triangles. Two vowel triangles were plotted for each mother, an IDS triangle and ADS triangle. R Software Environment, a free statistical program (http://www.r-project.org/), was used to plot tokens' F1 and F2 values. The mean values of F1 and F2 for three vowels (/i/, /u/, /a/) were used to create the points of the "vowel triangle", and the area of each "vowel triangle" was computed in R.

Vowel durations were also measured in Praat for the same tokens that created the vowel triangle. Vowels were isolated from token words by research assistants using the acoustic signal and spectrogram. Vowel duration was measured to the nearest thousandth of a second. The mean of the vowel durations for all of the point vowels (/i/, /a/, /u/) was calculated for each mother's IDS and ADS.

Vowel variability was calculated for each vowel in R using the formula, pi*sqrt(det(cov))/2, which calculated the area of the ellipses from the covariance matrix for F1 and F2 for each vowel category. This calculation provided a measure of the general spread of tokens within vowel categories. The variability values for each of the point vowels were averaged for each participant, and this mean value was used as a measure of overall vowel variability.

Quantity of IDS Analysis

The play session recorded second between 9.5 and 12 months of age was used for the quantity of IDS analysis. The FREQ list that was created for acoustic data selection was also used to identify non-words in the transcripts (e.g. sound effects/exclamations such as "hah", "oh", "uhoh"). These non-words were listed in an exclude text file, called "soundeffects.txt". The following command was then performed on the transcripts: freq +t*MOT – s@soundeffects.txt –s@childnames.txt. The output from this command provided values for the number of real word tokens and types in each transcript. Because the play sessions varied in length from about 8-18 minutes, the average number of tokens used per minute and types used per minute were calculated for each mother in order to make these values comparable across session lengths.

Outcome Measures

The participants returned to the lab when the children were 24-months of age in order to collect language outcome data. Testing sessions were performed by three research assistants that were not involved in the analyses described above. Children were administered the PPVT, EOWVT, and GFTA according to the standards described in the test manuals. Mothers were also asked to fill out the parent inventory, MCDI, to report on the words that their child says or attempts to say. Following each testing session, the PPVT, EOWVT and MCDI were scored by two independent scorers. When there was a discrepancy between the two scores, the scorers met to discuss the results and come to an agreement on a final raw test score, standard score, and percentile rank. The GFTA was scored using the audio recordings of the testing sessions, which were transcribed in CLAN. These CLAN transcripts allowed the scorer to listen to each target

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word multiple times before determining a phonetic transcription. Standard scores were used in this study for the EOWVT and GFTA. Because the PPVT is only standardized above 2 years 6 months of age, raw scores were used for this measure. Raw scores were also used for the MCDI.

Statistical Analyses

To examine whether vowel characteristics differ in IDS and ADS, three separate paired t-tests were calculated to compare 1) the vowel triangle areas in IDS and ADS, 2) the mean vowel durations in IDS and ADS, and 3) the mean of the areas of the ellipses for the point vowel categories in IDS and ADS.

To determine whether a relationship exists between maternal vowel clarity and infant language outcomes, we computed three separate sets of Pearson moment correlation coefficients to compare 1) the IDS vowel area values and the children's two-year outcome scores, 2) IDS mean vowel duration and outcome scores, and 3) mean of the ellipses areas in IDS and outcome scores. The *Peabody Picture Vocabulary Test* raw scores*, Expressive One-Word Vocabulary Test* and *Goldman Fristoe Test of Articulation* scaled scores, and MacArthur Communicative Developmental Inventory scores were used as measures of the children's vocabulary and articulation abilities at 2 years of age.

Reliability

To estimate interrater reliability for acoustic analyses, formant values and vowel durations for IDS and ADS tokens were measured by another research assistant for three mothers, representing approximately 12% of the total tokens in the study. Reliability was calculated with Pearson correlation coefficients between the two raters' values for F1, F2, and vowel duration. Inter-rater reliability results are shown in Table 1. A total of 382 tokens (12.4% of the total sample) were

analyzed by 2 raters. All measures were significantly correlated across raters, and, therefore, reliability of measures for F1, F2, and vowel durations was high.

Table 1: Reliability

	F1	F2	Vowel Duration
R value	0.92	0.93	0.97
p value	<0.0001	<0.0001	<0.0001

Results

Infant Language Outcome Data

Table 2 shows the summary of standardized language and articulation testing for the infants at age 24 months. Infants demonstrated some variability in testing scores. However, average test scores and standard deviations fell largely within the average range. The participants, therefore, represented a relatively homogeneous sample with very few children falling above or below the average range of abilities.

Table 2: Language and articulation test scores

	N Scores	Mean	Range	SD
PPVT (raw score)	21	28.86	8-59	13.86
EOWVT SS	20	96.9	59-110	14.98
MCDI (raw score)	21	315.19	24-489	128.56
GFTA SS	10	92	76-105	7.96

Vowel Clarity Summary Data

Words with target vowels were analyzed in 2 conditions, IDS and ADS, for 25 mothers. Vowel formants (F1, F2, F3) and vowel durations were measured for each vowel. Approximately 18% of eligible tokens were excluded from analysis due to overlapping speech or noise, lack of steady state as a result of co-articulatory effects or diphthongization, or voicing

issues such as whispering or glottal fry. For most mothers, more tokens were excluded in IDS compared to ADS because of the mothers' behaviors (e.g. diphthongization, whispering).

We analyzed 1659 vowels in each condition (total of 3318 tokens across conditions). An average of 65 tokens (range = 18-173) were analyzed for each mother in each condition. Following examination of the number of tokens available per vowel category for each mother, a minimum of at least 8 tokens in an individual vowel category was required for mothers to be included in future analyses. Four mothers were excluded using this criterion, leaving 21 mothers in the final analysis. Therefore, 3,078 tokens were included in the final analysis. Table 3 shows the summary of tokens available for the 21 mothers that were included in final analyses.

Table 3: Summary of tokens available for each vowel, per condition for 21 mothers.

	Mean	Range
/a/	14.4	9-41
/i/	25	10-56
/u/	19.9	9-62
/U/	13.9	8-34
Total tokens per mother	73.2	35-173

Comparisons among vowel clarity measures

Mean vowel duration was calculated for each vowel and then averaged across the point vowels. Interestingly, vowel space and mean vowel duration for the point vowels were not significantly correlated to each other in either condition (IDS r(19)=0.34, p=0.13; ADS r(19)=0.06, p=0.78). Vowel variability did not correlate significantly with either vowel space (IDS r(19)=2.6, p=2.5; ADS r(19)=0.005, p=0.98) or vowel duration (IDS r(19)=0.24, p=0.29; ADS r(19)=0.14, p=0.53).

We also calculated vowel space using the method described by Monahan and Idsardi (2010) using F1/F3 by F2/F3 ratios. This method allows for more normalization across speakers

and would allow for less variation due to individuals' vocal tract size and shape. See Table 4 for results. The vowel space measures calculated using the traditional F1 by F2 triangle and those calculated using the F1/F3 by F2/F3 ratio triangle were highly correlated for both conditions (IDS r(19)= 0.92, p<0.00001; ADS r(19)=0.8, p=0.00001). The traditional F1 by F2 vowel space measures were used for all further analyses since most previous studies of IDS vowel clarity used these methods.

Comparison of Vowel Clarity in IDS versus ADS

Two-tailed paired t-tests were performed to determine whether there was a significant difference in vowel space area, vowel durations or vowel variability in the IDS condition versus ADS. The significance level was set to p=0.017 to adjust for the three t-tests performed. See Table 4 for summary data.

Table 4: Summary of vowel space, duration and variability data (N=21)

	ADS			IDS			t-test results
	Mean	**Range**	**SD**	**Mean**	**Range**	**SD**	
Vowel space (F1 by F2) – all tokens (Bark)	15.28	10.9-18.98	2.65	16.99	9.03-23.53	4.15	t(20)=1.67, p=0.063
Vowel space area (F1/F3 by F2/F3) (Bark)	0.0533	0.0311-0.0713	0.0115	0.0575	0.0332-0.0848	0.0152	t(20)=1.29, p=0.196
Vowel space (F1 by F2)– content words (Bark)	21.64	8.81-35.49	6.86	18.63	11.69-29.17	4.6	t=2.73, p=0.013**
Vowel space (F1 by F2)– function words (Bark)	13.19	6.83-17.18	3.2	12.65	8.1-18.47	2.9	t=0.56, p=0.58
Vowel duration - /a/ (s)	0.152	0.103-0.226	0.031	0.149	0.079-0.238	0.042	t(20)=-0.29, p=0.77
Vowel duration - /i/ (s)	0.123	0.076-.183	0.026	0.132	0.064-0.224	0.045	t(20)=1.07, p=0.30
Vowel duration - /u/ (s)	0.137	0.093-0.176	0.026	0.161	0.067-0.338	0.058	t(20)=1.87, p=0.07
Mean vowel duration (s)	0.137	0.102-0.185	0.021	0.148	0.073-0.22	0.031	t(20)=1.71, p=0.10
Mean vowel duration – content words (s)	0.197	0.079-0.33	0.058	0.17	0.1-0.22	0.029	t=2.98, p=0.007**
Mean vowel duration – function words (s)	0.095	0.074-0.13	0.013	0.11	0.078-0.14	0.015	t=-3.77, p=0.001*
Mean vowel variability	0.968	0.563-1.40	0.214	1.33	0.675-1.95	0.352	t(20)=4.1, p=0.0005*

*Significant at p=0.017
** Significant at p=0.025

Figure 3 shows a line graph of vowel space measures for the 21 mothers in IDS and ADS. No significant difference was found between conditions for vowel space area (t(20)=1.67, p=0.063). Similarly, no significant differences were found between conditions for individual or overall vowel durations (t(20)=1.7, p=0.10). See Figure 4 for line graph of mean duration values. However, a significant difference was found between mean vowel variability in IDS and

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ADS, with greater variability in IDS (t(20)=4.1, p=0.0005) (see Figure 5). That is, the ellipses

covering the tokens within each vowel category were larger in IDS compared to ADS.
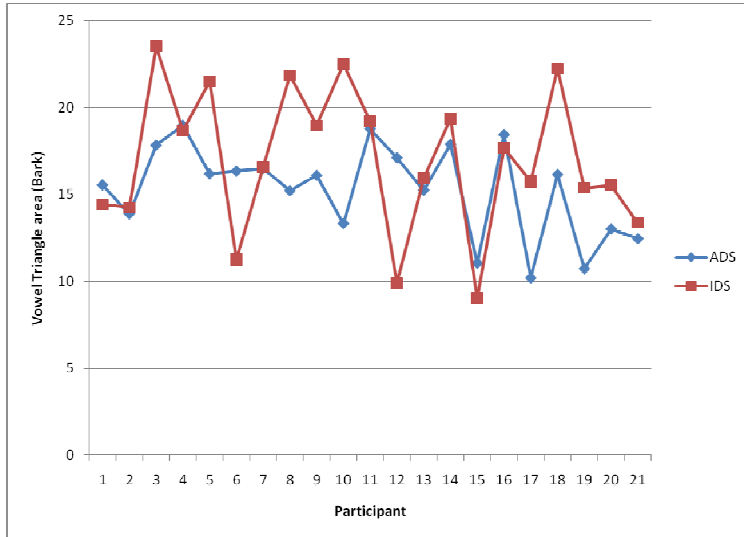

Figure 3: Vowel Triangle Areas in IDS and ADS

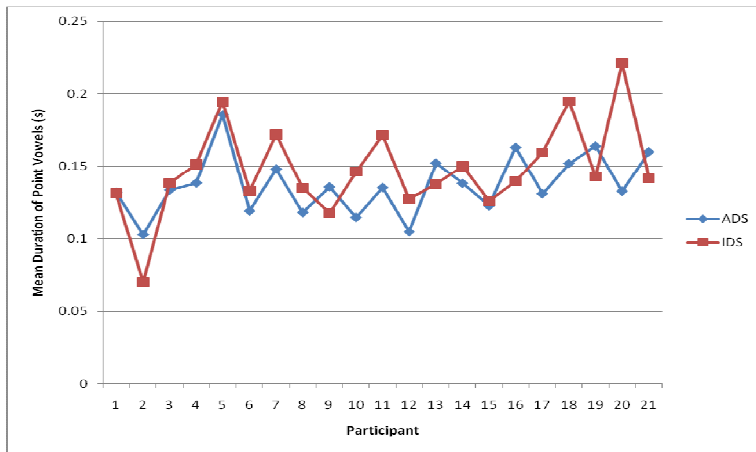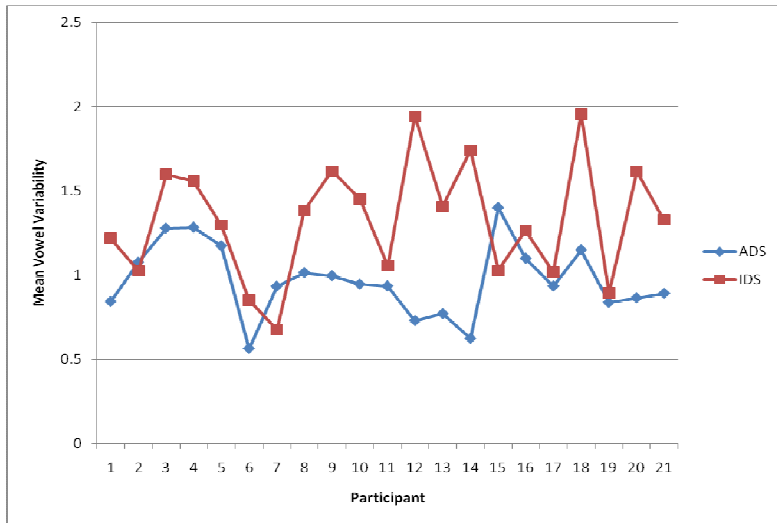
Figure 4: Mean Vowel Durations in IDS and ADS

Figure 5: Mean Vowel Variability in IDS and ADS

Figure 6 shows vowel triangle plots for all tokens from the 21 mothers. Although patterns were variable within individual mothers, an overall pattern of expansion is seen in IDS along with greater variability within the /u/ and /a/ vowel categories.
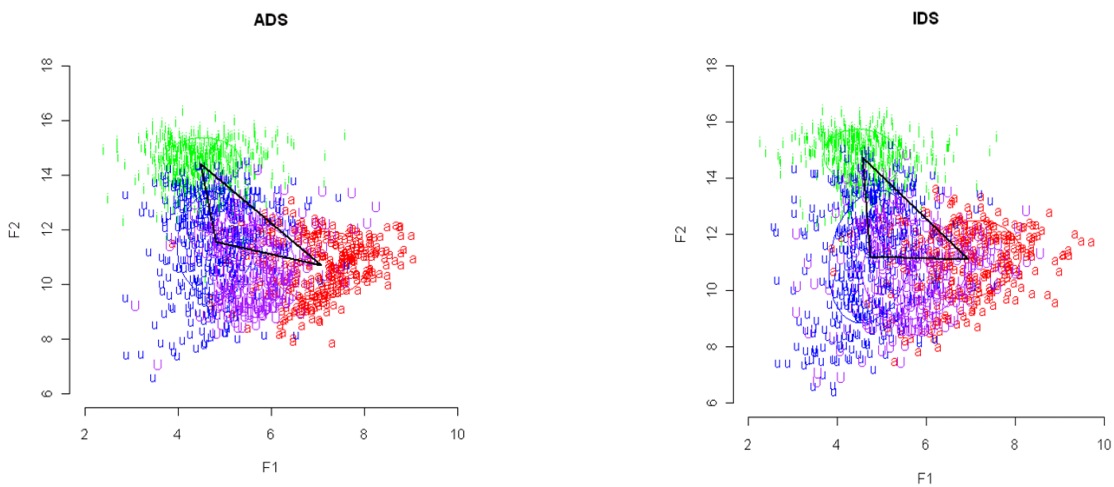
Figure 6: Vowel plots for all mothers combined.

Some mothers had a bigger vowel space in IDS compared to ADS while others showed the opposite pattern. See Figures 7 and 8 for examples.
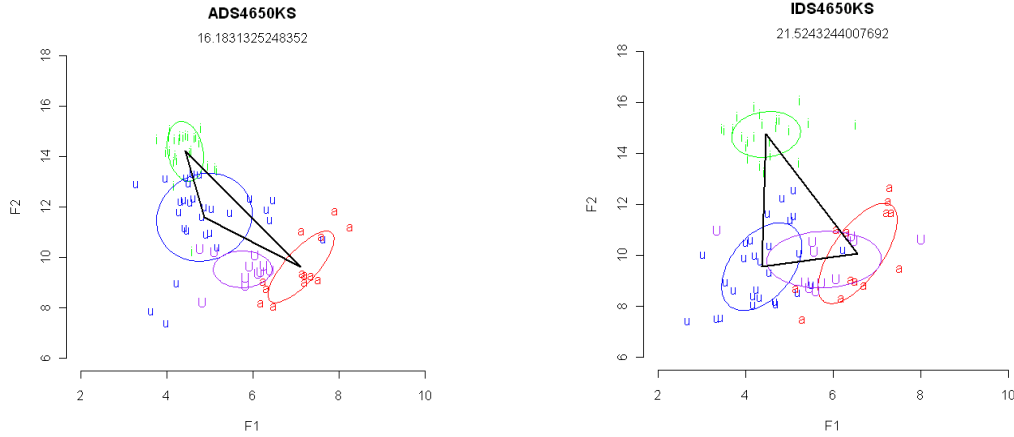
Figure 7: Example of mother who showed expansion of vowel space in IDS (right graph).
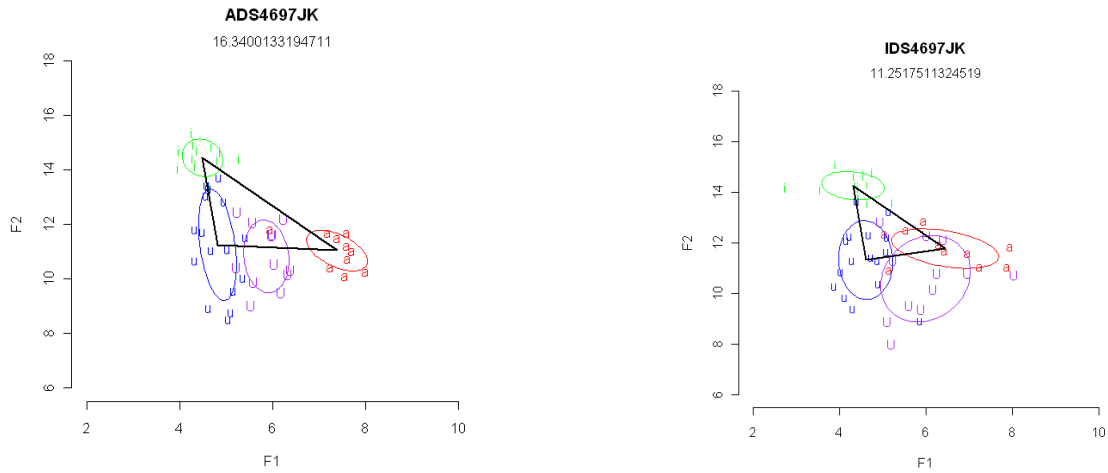
Figure 8: Example of mother who showed reduced vowel space in IDS (right graph).

Content versus Function Words Analyses

The above analyses of vowel clarity included both content and function words. However, previous studies of vowels have found that vowel clarity of function words in maternal IDS does not occur until children are using more advanced expression (Bernstein Ratner, 1984).

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Additionally, most previous studies of vowel clarity in IDS focus mostly on content words (Song, 2009; Englund & Behne, 2006). Therefore, we also broke down our hypotheses by word class for the two vowel clarity measures in which no significant difference was found between IDS and ADS – vowel space and vowel duration. We set the p value to 0.025 to adjust for the correlations within the 2 word classes. After separating content and function words, fewer tokens overall and for each vowel category were available for these analyses, so the results should be interpreted with caution. One dyad did not have /a/ tokens available for function words. Therefore, function word specific data were available for only 20 of the dyads.

Results of the t-tests comparing IDS and ADS by word class are found in Table 4. A significant difference was found between vowel space area for content words in IDS compared to ADS (t(20)=2.73, p=0.013), such that vowel space was larger in IDS than ADS, but this result was not found for function words (t(19)=0.56, p=0.58). Similar results were found for vowel durations in content words (t(20)=2.98, p=0.007), showing that vowels in content words were significantly longer in IDS compared to ADS. However, vowels in function words were significantly shorter in IDS compared to ADS (t(19)=-3.77, p=0.001). Thus our prediction that mothers would produce longer and more clarified vowels when addressing infants was supported, but only for content words and not function words.

Relationship between IDS vowel clarity measures and 24-month language outcomes

Pearson correlation coefficients were calculated to determine whether a relationship existed between maternal vowel clarity measures to children at 9.5-12 months of age and the children's language scores at 24-months. The p-value was set at 0.005 to adjust for the 9 correlations. See Table 5 for results of these analyses. One child did not complete the EOWVT

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test, so only 20 dyads were available for the EOWVT correlation analysis. Twenty-one dyads

were available for the MCDI and PPVT correlation analyses. The F1 by F2 vowel triangle areas

were used for these analyses. No significant correlations were found between IDS vowel space

area and expressive language outcomes (EOWVT r(18)=-0.002, p=0.99; MCDI r(19)=0.196,

p=0.39), or between IDS vowel space area and receptive language outcomes (PPVT r(19)=-

0.077, p=0.74).   Non-significant negative correlations were found between overall IDS vowel

duration and language scores (EOWVT r(18)=-0.24, p=0.31; MCDI r(19)=-0.076, p=0.74; PPVT

r(19)=-0.49, p=0.024). These negative correlations were the opposite from what we had

predicted. Vowel variability in IDS did not relate significantly to any of the language outcome

measures (PPVT r(19)=0.08, p=0.73; EOWVT r(18)=0.01, p=0.96; MCDI r(19)=0.013, p=0.95).

Table 5: Correlation coefficients for IDS vowel clarity, Quantity of Language, and Outcome
Measures

		EOWVT	MCDI	PPVT	GFTA
Vowel space	All tokens	r(18)=-0.002	r(19)=0.196	r(19)=-0.077	r(8)=0.12
	Content words	r(18)=0.085	r(19)=0.05	r(19)=0.017	r(8)=0.06
	Function words	r(17)=-0.2	r(18)=-0.08	r(18)=-0.16	r(7)=0.15
Vowel duration	All tokens	r(18)=-0.24	r(19)=-0.076	r(19)=-0.077	r(8)=0.19
	Content words	r(18)=-0.37	r(19)=-0.29	r(19)=-0.49	r(8)=0.05
	Function words	r(17)=0.19	r(18)=0.2	r(18)=0.05	r(7)=-0.17
Vowel Variability		r(18)=0.01	r(19)=0.013	r(19)=-0.08	r(8)=0.056
Tokens (tokens/ minute)		r(18)=0.09	r(19)=0.08	r(19)=-0.08	n/a
Types (types/ minute)		r(18)=-0.11	r(19)=-0.17	r(19)=-0.04	n/a

No measures were significant at p=0.005

Relationship between Word Class Clarity and Outcomes

We also examined whether a relationship existed between vowel clarity measures for

content or function words and outcome measures. Results of these analyses are shown in Table

5. No significant relationships were found between vowel space in IDS content words and

receptive language scores (PPVT r(19)=0.017, p=0.94) or expressive language scores (EOWVT

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r(18)=0.085, p=0.72; MCDI r(19)=0.05, p=0.82). On the other hand, non-significant negative correlations were found between vowel space in function words and language outcomes (PPVT r(18)=-0.16, p=0.5; EOWVT r(17)=-0.2, p=0.4; MCDI r(18)=-0.08, p=0.73). Although these correlations were not significant, it is interesting to note that children whose mothers used a larger vowel space for their function words actually scored lower on standardized language measures.

Unlike vowel space, mean vowel duration for content words was negatively related to language outcome measures. This relationship was not significant for receptive language scores (PPVT r(19)=-0.49, p=0.02) or for expressive language scores (EOWVT r(18)=-0.37, p=0.11; MCDI r(19)=-0.29, p=0.2). No significant relationships were found between mean vowel duration of function words and outcome measures (EOWVT r(17)=0.19, p=0.43, MCDI r(18)=0.2, p=0.4; PPVT r(18)=0.05, p=0.83). Although the relationships were not significant, vowel duration of function words appeared to be positively related to language outcomes, such that as vowel duration of function words in IDS increased, language outcome scores also increased.

Relationship to Articulation Outcomes

Because vowel clarity is used as a proxy for overall speech clarity, we also examined whether maternal speech clarity impacts the children's articulation abilities using the Goldman Fristoe Test of Articulation (GFTA) scores at 24-months. Only 10 of the 21 children in this sample completed the GFTA. Because language testing was a higher priority for these analyses, the GFTA was administered at the end of the testing session, and therefore, several of the toddlers were non-compliant at this point in the session and did not complete the test. When more than 10% of the target sounds were not elicited, scores were excluded from this analysis.

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Seven of the 10 children included in this analysis had up to 7 target sounds that were not elicited during testing. In these cases, children were given credit for these non-elicited items. Pearson correlation coefficients were calculated to compare the IDS vowel space and vowel duration measures and the 10 GFTA standard scores that were available. Results are shown in Table 5. No significant correlations were found between GFTA standard scores and vowel space in IDS (r(8)=0.12, p=0.74); GFTA SS and vowel space of content words (r(8)=0.06, p=0.86), or GFTA SS and overall mean vowel duration (r(8)=0.19, p=0.59). No significant correlation existed between vowel variability and GFTA SS (r(8)=0.056, p=0.88).

Group Comparison

In addition to correlations, we compared outcome scores for 2 groups of participants – those with "clarified" vowels and those with "non-clarified" vowels. The "clarified" group was defined as mothers whose overall IDS vowel space (i.e. including both function and content words) was at least 1 bark greater than their ADS vowel space. The "non-clarified" group was defined as mothers whose IDS vowel space was within 1 bark or less than the ADS space. Bark units represent perceptually noticeable differences in sound, so a difference of 1 bark was required for a mother's vowels to be considered clarified. We expected that children who received the clarified input would demonstrate better outcome scores than the other group. Average outcomes measures for each group and t-test results are shown in Table 6. Because of the small number of GFTA scores available, this outcome measure was not compared in this analysis. Two-sample t-tests were run to compare outcomes for the two groups. Because one of the comparisons failed testing of equal variance, we used non-parametric results. Mann Whitney U converted to Wilcoxon Z results showed no significant differences between the groups for any of the language outcome measures. Average scores for the PPVT and EOWVT were actually

larger in the non-clarified group, contradicting our original hypothesis that children who received

more clarified speech would demonstrate better language skills.

Table 6: Results of Wilcoxon Z comparison for "Clarified" and "Non-Clarified" group outcomes

	Clarified Group	Non-Clarified Group	Z scores
PPVT mean raw scores	27.4	30.54	Z(19)= -0.32 p=0.75
EOWVT mean SS	92.67	98.27	Z(18)=-1.18 p=0.23
MCDI mean raw scores	325.9	305.27	Z(19)=0.74 p=0.46

Quantity of Language Analyses

In addition to vowel clarity measures, we also examined the relationship between

quantity of language in IDS and language outcomes. No significant relationships were found

between mean number of tokens or types used per minute and language outcomes. See Table 5

for results of these statistical analyses.

Discussion

Some differences were found between vowel clarity in IDS versus ADS, but many of our measures did not show the differences that we predicted. The only measure that resulted in a significant difference between the entire samples (i.e. including both content and function words) was our measure of vowel variability. Variability within vowel categories has not been used frequently in studies of mother-child speech. However, it is an interesting find that vowel variability was larger in IDS compared to ADS. It is possible that increased variability also led to increased overlap among vowels, especially considering the lack of correlation between vowel space and variability. On the other hand, it is possible that the selective over-articulation of "target words" combined with reduction of more predictable or non-targeted words, resulted in larger variability within the IDS samples. For the other measures of vowel clarity used in this study (i.e. vowel space and vowel duration), differences between IDS and ADS only emerged when content words were examined separately from function words. These differences did not exist for the overall speech samples (i.e. content and function words combined). This lack of vowel clarification in the overall speech sample to prelinguistic listeners was similar to those found by Englund and Behne (2006) who actually found a smaller vowel space in IDS compared to ADS. However, other studies did find larger vowel spaces in IDS to prelinguistic infants (Bernstein Ratner, 1984; Kuhl et al., 1997). More studies examining the changes to vowels in IDS compared to ADS and at different infant ages may be beneficial given the contradictory research currently available.

One unique aspect of our study was that our initial vowel clarity calculations included both function and content words. Some previous studies of vowel space in IDS focused primarily or solely on content words (Englund & Behne, 2006; Song, 2009). When the data

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were separated by word class (content or function), significant differences were found between IDS and ADS. Content words in IDS had a significantly larger vowel space and longer mean vowel duration than those in ADS. However, no significant difference was found between vowel space for function words in IDS and ADS, and mean vowel duration in function words was actually significantly shorter in IDS compared to ADS. Our results indicated that vowel space expansion and elongation occur for content words in IDS but not for function words at this prelinguistic stage. In a study which included analysis of function words in IDS, Bernstein Ratner (1984) did not find a noticeable difference between IDS and ADS vowel space for function words until children were using more advanced forms linguistic expression (3-4 word stage). Therefore, it is possible that mothers do not clarify function words until they know that their children have actually begun to learn and use these forms themselves.

Our finding that not all vowels in IDS were more clarified compared to ADS vowels across all measures supports the theory argued by Kirchhoff and Schimmel (2005) that "adults might reduce predictable words more when talking to their infants/children than when talking to adults in order to draw the child's attention to referents that are new in the discourse or in the extralinguistic environment" (p. 2245). By reducing the clarity of more predictable words, like function words, the mother may be making the more important or novel words more salient and clearer within the speech stream (Kirchhoff & Schimmel, 2005). Although mothers appear to clarify words most when they are considered to be novel to their children (Bernstein Ratner, 1996), they may also reduce previously learned content words in addition to function words. Lack of stress of some words in fluent speech is also necessary to convey the prosodic and rhythmic cues that help listeners understand speech (Peters & Stromqvist, 1996). Therefore, mothers may demonstrate a greater difference between the clarity of key words, typically content

words, and the lack of clarity of function words or non-targeted content words in IDS. Such an exaggeration between clarity and lack of clarity may actually be more beneficial than simply increasing overall clarity of all words in IDS.

Relationships between IDS variables and language outcomes

Relationships to language outcomes varied for the measures of vowel clarification. No significant relationships were found between vowel space and vowel variability measures and language outcomes.   However, interesting relationships were found between vowel durations and outcomes measures. Although results were not significant, increases in vowel duration in IDS generally were correlated with lower language scores. These results seem to support the notion that longer vowel durations might not actually result in clearer speech, although a causal relationship between maternal vowel durations and poorer outcomes can obviously not be argued in this study. It is also possible that children with less advanced skills might prompt slower speech from their mothers. Of course, this hypothesis rests on the assumption that these poorer language abilities are in some way apparent to their caregivers over a year earlier. On the other hand, longer vowel duration in function words was positively, though non-significantly, related to all language outcomes.   Because vowel duration in function words was actually significantly shorter in IDS than ADS, these increases in vowel duration probably do not indicate better vowel clarity but, rather, "less bad" vowel articulation.

In general, measures of vowel clarification in IDS did not relate significantly to language or articulation outcomes. Our results support the results from Song's study (2009) which also did not find significant relationships between vowel clarity and vocabulary abilities or between quantity of IDS and longer term outcomes. It is possible that vowel clarification is not an

important factor in maternal input at these prelinguistic ages and may become more significant later in development as the children become more advanced language users. Even within IDS there are several variables that may relate to language learning, including semantics, syntax, prosody and non-verbal aspects of turn-taking or joint attention. Vowel clarification is also only one of several factors that have the potential to impact language development. Although vowel clarity may potentially benefit speech perception abilities, it does not appear to be a driving factor in predicting long term outcomes at this stage of language learning.

Further, it could be argued that maternal IDS may not have as significant of a role in long-term language development as is often assumed in studies of IDS. Many studies have based their hypotheses on the assumption that maternal IDS is the primary source of language input to infants during their early years, but these studies do not usually report information regarding whether this is actually the case. In our study, only a limited number of the children were cared for primarily by their mothers during the work week, and even these children would most certainly have been exposed to a significant amount of language from other speakers during their first two years of life. Additionally, the children in our study represented a relatively limited range of language abilities. Most speech and language testing scores fell within the average range with very few remarkably poor or exceptional scores. These children may already possess the skills necessary to learn from a wide range of speech qualities from a variety of speakers. These participant characteristics may have minimized the influence of maternal IDS on long-term language outcomes.

Our study focused on the relationship between maternal vowel clarity and infant vocabulary outcomes at 2-years of age, prior to the point when most children begin using syntax. However, Nespor, Pena and Mehler (2003) argued that vowels convey more information about

syntax while consonants are more important for the lexical meanings based on a review of perceptual studies with adults. Thus an examination of the relationship between maternal vowel clarity and children's later syntax abilities may be an interesting future study. Recent research has examined differences in consonant production in IDS and ADS. Cristia (2010) found that sibilants were enhanced in IDS to older infants as compared to ADS but this enhancement did not occur to younger infants. This study did not include a longitudinal comparison of infant language abilities but suggests that future research may be done to compare consonant changes in IDS to infant language abilities (Cristia, 2010).

Quantity of Language Results

Our hypotheses that higher quantities of language input would relate to language outcomes were not supported in this study. However, our sample was a relatively homogeneous population of mothers who were mostly middle class and well educated, so it is likely that all of these children were receiving an adequate quantity of language input throughout their development. Therefore, the variability seen in the input during our short play sessions may not have been meaningful. Additionally, it is possible that children who were more advanced in their turn-taking or babbling offered fewer opportunities for the mothers to provide language input. Sampling quantity of language input over a longer period of time or with a more diverse population of children/mothers might result in stronger correlations.

Vowel clarification Methodology

We did not find a significant correlation between any of the measures of vowel clarification used in this study. This disconnect among the different measures brings up a question of how to best define "vowel clarity". Unlike other acoustical measures of

conversational speech (e.g. voice onset time, pitch), results of vowel analyses are highly affected by variations in duration, diphthongization, and coarticulation. Intuitively, it makes sense that better vowel clarity would be ideally defined as a larger vowel space with smaller variability within classes and longer durations of monophthongs. However, these changes do not appear to happen in a varied sample of words from running conversational speech, at least not in any systematic or predictable way. Previous studies have found a correlation between vowel space and duration (e.g. Song, 2010). However, another study did not find a systematic relationship between vowel duration and vowel formant values in IDS or ADS (Bernstein Ratner, 1985). Our measure of vowel variability, which was based on variability within vowel categories across several individual tokens, did not correlate with vowel duration or vowel space. However, vowel elongation in IDS often appeared to coincide with greater variation of vowel formants within the individual tokens in our sample, through diphthongization or variations in prosody. That is, longer vowels may have actually contained shorter steady states in proportion to the entire length of the vowel in comparison to shorter vowels. We did not quantify this measure in the present study, but it may be an interesting topic for future research.

The majority of mothers showed greater vowel variability in IDS compared to ADS independent of changes in vowel space or duration. It is possible that this increase in variability nullified any benefit that vowel space expansion could have provided to the infants. Descriptively, increased variability within vowel categories also tended to lead to more overlap among the vowels (see Figure 9 for example). Based on results of a study of perceptual skills of people with cochlear implants, it has been hypothesized that increased variability and spread within perceptual vowel categories may lead to increased difficulty in discriminating among the phonemes (Harnsberger, Svirsky, Kaiser, Pisoni, Wright & Meyer, 2001). Likewise, infants who

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are exposed to vowel categories with large variability may have more trouble discriminating among the vowels and decoding speech. On the other hand, it could be assumed that vowel variability increases with vowel space without increasing overlap between categories, but our results did not show this systematic relationship between vowel space and variability. Therefore, it may be more important to measure distinctiveness among vowels than overall vowel space (Neel, 2008).
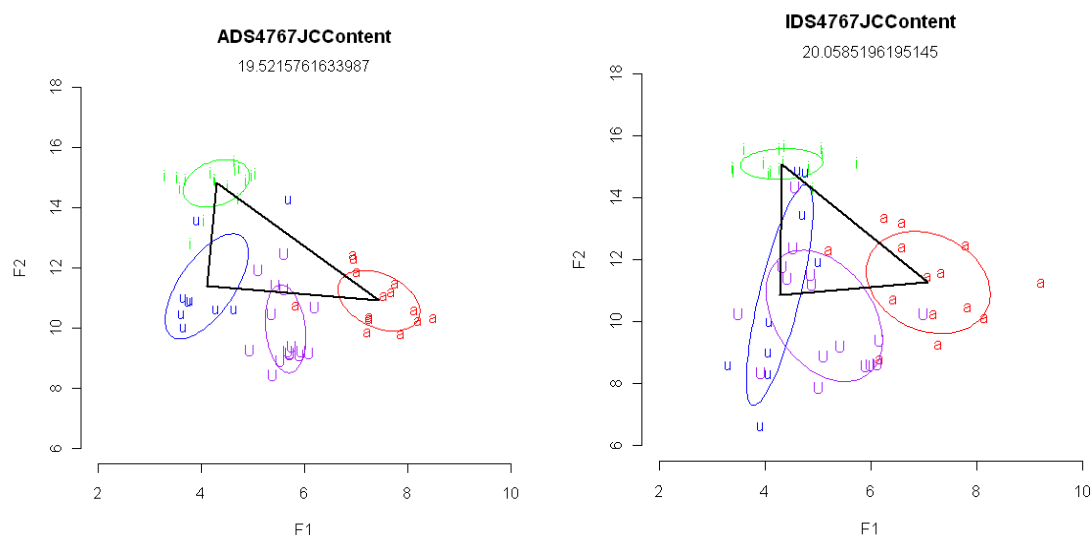

Figure 9: Plots of vowel triangle for content words in ADS and IDS for the same mother. Overall vowel space increases in IDS but variability within vowel categories (seen in larger areas of the ellipses) also increases.

Acoustic analysis of vowels has been performed in several different ways in the research. Though we measured the formants at the midpoint of the study state, other researchers have taken different approaches. Kuhl and colleagues (1997) measured formants at the beginning, middle, and end of the vowel. Englund and Behne (2006) averaged formant values for all points within the vowels. With our method of measuring the midpoint of the steady state of the target vowel, only one point within the vowel was selected for the formant values. Although this could

have led to some variability across vowels due to the subjectivity of selecting a point along the diphthong to analyze, formant excursions within each of the individual vowels were ignored since only a single point value was ultimately selected. It is possible that measuring the mean formant values for the entire length of the vowel would have allowed for more accurate representation of diphthongized vowels, vowels distorted by pitch changes or proximity to liquids and glides. Vowel space and vowel duration may have been more correlated using these alternative methods.

There are also alternative ways to plot the vowels and calculate vowel space from the formant values measured. We chose to normalize our data by converting Hertz to Bark values, but most previous studies used Hertz values. In addition, we measured vowel space using both the F1 by F2 triangle and the F1/F3 by F2/F3 triangle described by Monahan and Idsardi (2010). We found a strong correlation between these measures, and, therefore, focused on the more traditional vowel space (F1 by F2) in calculating correlations with later outcomes. However, it is possible that changes in methodology for measuring formants and plotting vowel space might lead to different results.

Directions for Future Research

Longitudinal analysis of the relationship between maternal IDS and concurrent and later language abilities warrants additional research. However, relationships may be more likely between maternal vowel clarity to older children who are already using language and the children's concurrent language abilities. Relationships between vowel clarity and language outcomes may also become more apparent at later ages when there is less of a gap between input and outcomes. Comparisons of maternal language input across different cultures and their

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relationships to language outcomes would also be valuable. Because we did not find interesting relationships between vowel clarity and outcomes, other aspects of IDS during the prelinguistic stage, such as semantics, syntax, or prosody, may be examined to determine their potential impact on language outcomes. A very limited number of studies have examined these relationships longitudinally, although knowledge of these relationships could potentially be beneficial in providing recommendations for early intervention in at-risk populations.

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