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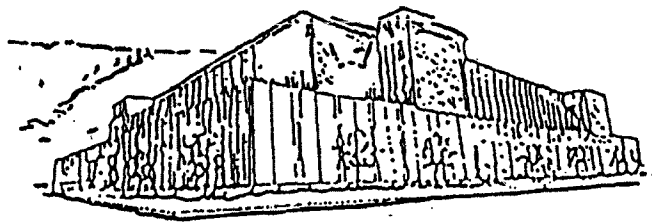
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Fundamental Frequency In Speech Directed To
Deaf or Hearing Infants by Deaf or Hearing Mothers

by

Meg Ann Traci

B.S. The University of Wisconsin-Madison, 1990

presented in partial fulfillment of the requirements

for the degree of

Master of Arts

The University of Montana

1998

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Traci, Meg A., M.A., May 1998

Fundamental Frequency In Speech Directed To Deaf or Hearing Infants by Deaf or Hearing Mothers (60 pp.)

Director: Lynne Sanford Koester *Lynne Sanford Koester*

This study investigated the acoustical properties of "motherese" in interactions between Deaf or hearing mothers and their deaf or hearing nine-month-old infants. It was assumed that levels of maternal auditory functioning would have an impact on the pitch modulation in infant-directed (ID) vocalizations. Furthermore, it was proposed that the specific communicative functions of ID pitch modulation, as hypothesized in the "motherese" literature, may be accomplished by other communicative forms more appropriate to the sensory capacities of a deaf infant; these other communicative modalities, such as visual-gestural, are typically inherent in the communicative style of a deaf mother. Data were derived from videotaped observations of 53 mothers during face-to-face interactions with their infants. Summary measurements of the fundamental frequency of maternal vocal utterances revealed that maternal hearing status and infant hearing status affected the mean level of pitch and of pitch variability. Theories of intuitive parenting, cultural difference, and motherese guide conclusions generated from the results.

Acknowledgements

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Table of Contents

Abstract	ii
Acknowledgements	iii
I) Introduction	1
A. Communication With the Prelingual Infant	4
B. Studies of Motherese in Sign Languages	6
C. The Impact of Deafness On Early Development	9
D. Quantifying Pitch	11
1. Dynamic measurements	14
2. Summary measurements	16
E. Functional Explanations of Motherese	17
1. The linguistic function of motherese	19
2. The attentional function of motherese	21
3. The social/affective function of motherese	21
F. Summary and Purpose of Study	22
1. Deaf mother/deaf infant	22
2. Hearing mother/deaf infant	23
3. Deaf mother/hearing infant	24
4. Hearing mother/hearing infant	26
5. Summary	26
6. Hypotheses	26
II) Method	28
A. Participants	28
1. Special characteristics of Deaf participants	30
2. Hearing aids	31
3. Early intervention	31
B. Procedure	32
1. Observation procedure	32
2. Data reduction and analysis	33
III) Results	38
A. The Mean F_0 and Its Standard Deviation	38
B. The Mean Range (Lowest to Highest) in Hertz and Semitones	39
C. The Mean Range (Starting to Ending in Hertz and Semitones	40
IV) Discussion	44
A. Characteristics of ID Speech in Deaf Mother-Deaf Infant Dyads	45
B. Unexpected Findings and Possible Explanations	48
C. Conclusions	53
V) References	56

Figures and Tables

Figure 1: Spectrographic Displays (Grieser and Kuhl, 1988) 15
Figure 2: Wavefile, Sound Spectrogram, and Power Spectrum 43

Table 1: Descriptive Information of Participants by Group 35
Table 2: Means of Summary Measurements of the Fundamental Frequency in ID
Speech by Group 43

Fundamental Frequency In Speech

Directed To Deaf or Hearing Infants by Deaf or Hearing Mothers

During the past three decades, developmentalists, linguists, and anthropologists have been investigating the language adaptations that adults make to communicate with infants and young children. These adult modifications of semantics, syntax, and acoustics result in a unique language pattern most commonly referred to as motherese, but it has also been referred to as 'babytalk' (BT), infant-directed (ID) speech, adult-infant(A-I) speech, and most recently, 'parentese.' The terms, ID and A-I speech, especially reflect the traditional research focus of motherese as a strictly vocal phenomenon. Studies of motherese in sign languages (discussed below) have shown that this focus and those terms are far too limited because motherese is used in nonvocal languages, too. Therefore, for the purposes of this research project, *motherese* will be used to refer to the broader phenomenon of adult language adaptations made in A-I interactions while *ID speech* or *A-I speech* will be used interchangeably to refer to vocal patterns that vary from adult-adult (A-A) interactions to A-I interactions.

This project investigated one aspect of the motherese phenomenon as it occurred in mother-infant interactions in which the mother was either Deaf¹ or

¹ Within the Deaf community, a usual convention is to denote the audiological condition of being deaf with a lower-case "d" and to denote the cultural and linguistic identity of being Deaf with a capital "D." It is possible that a deaf as well as a hearing infant could be described as Deaf given that his/her parents are actively involved in the Deaf community and use American Sign Language (ASL) as their primary language. However, it is unclear whether this distinction of being

hearing and the infant was either deaf or hearing. It was proposed that Deaf and hearing mothers of deaf and hearing infants would express ID speech with different patterns of pitch modulation. Pitch would be expected to vary among mothers belonging to different cultures (Stokoe, 1989) and among mothers intuitively attuning their parenting styles to the specific needs of their infants (Papoušek & Papoušek, 1987).

It was proposed that the primary language of the mothers, English or American Sign Language (ASL), would predict cultural differences that would be reflected in different patterns of pitch modulation used in ID speech (Stokoe, 1989). In the Deaf American Culture (DAC), the specific communicative functions of ID pitch modulation hypothesized in the motherese literature would also be accomplished by other communicative forms (e.g. visual-spatial modalities) which are more suited to the sensory capacities of a deaf infant or more familiar to the communicative style of a Deaf mother. Stokoe (1989) used Hall's matrix of 100 cells entitled "A Map of Culture", in order to outline some of the cultural differences between DAC and the Mainstream American Culture (MAC; i.e. hearing and English speaking). Stokoe suggests content for several of the matrix's cells that would be necessary in mapping DAC. A relevant example is as follows:

Deaf may only be made by an individual who is developmentally ready to choose to identify with a culture. For purposes of consistency and clarity, I will describe infant participants of this research project in terms of their audiological condition with the acknowledgement that it may be more accurate to describe some of the participating children as Deaf. Since the Deaf mothers were almost exclusively recruited from the Gallaudet community, I will refer to them with the capital "D."

To calibrate the map for DAC and all other Deaf cultures, it is best to begin in the key Cell, 00. Its label, "Communication, Vocal qualifiers, Kinesics, Language," needs a minor change, to: "Communication, Pantomime, Gesture, Language." The change of only two of the terms may look slight, but it is of the utmost importance" (p.55).

Indeed, the minor change Stokoe suggests may be important to our understanding of how and when different patterns of pitch modulation are used in ID speech, and to whether we continue to use 'ID speech' and 'motherese' as synonymous terms.

In addition to cultural differences, it was also proposed that mothers' intuitive responses would reflect the different communicative needs of deaf and hearing infants. Papoušek and Papoušek's theory of intuitive parenting (1990) asserts that within didactic, interactional systems, the more competent partner (e.g., the parent) will make accommodations in behavioral styles in order to make his/her knowledge accessible to the less competent partner (e.g., the infant). So, a hearing mother may use visual-spatial modalities more to communicate with a deaf infant than with a hearing infant, and a Deaf mother may use vocal modalities more to communicate with a hearing infant than with a deaf infant.

To summarize, the current study explored whether the motherese phenomenon would be expressed in the ID speech of mothers whose culture uses a visual-gestural language rather than a vocal/oral language. To answer this question, acoustic analyses were performed to quantify the pitch frequencies

and variability used by Deaf and hearing mothers communicating with deaf and hearing infants. Hypotheses were generated from a functional analysis that incorporated both cultural theory and the theory of intuitive parenting.

Communication With the Prelingual Infant

Facial expressions (Papoušek & Bornstein, 1992), eye gaze (Koester, Karkowski, & Traci, 1998), and touch (Gusella, Muir, & Tronick, 1988; Stack & Muir, 1990), are important components of communication in early interactions between adults and prelingual infants, and they are differentially used when adults are communicating with adults as opposed to infants. However, unless facial expressions, eye gaze, and touch are communicative forms primarily reserved for formal language production, adjustments adults make when using them in interactions with infants do not conventionally qualify them as forms of motherese. A verbal adult who is communicating to an infant and who is differentially using communicative elements such as syntax, semantics, and acoustics to do so, would be demonstrating motherese. The differential use of the acoustic elements has been most commonly used in the motherese literature to quantitatively represent the 'melodic' quality of ID speech.

The acoustic elements of human vocalizations are described as components of prosody and as paralinguistic features. Katz, Cohn, and Moore (1996) specifically identified these acoustic variables in their definition of prosody:

... pitch, the psychoacoustic percept corresponding roughly to vocal fundamental frequency; loudness, the psychoacoustic percept of intensity;

and rhythm, which is related to speech rate and patterning. (p. 206)

Garnica (1977) distinguished the prosodic use of pitch, loudness, and rhythm from the paralinguistic use of these vocal dimensions. Prosody, she described, can mark lexical and grammatical qualities in a language while paralinguistics indicate emotional or attitudinal aspects of communication. Pitch, loudness, and rhythm function prosodically to convey linguistic information and paralinguistically to communicate affective information. The prosody of pitch is exemplified by its ability to indicate semantic meaning in tonal languages such as Mandarin Chinese and to distinguish a question from a command as it does in English, a nontonal language. The paralingual quality of pitch is illustrated by its ability to convey comfort, approval, and levels of social engagement (for a review see Shute, 1987).

ID speech is usually described as having a higher overall pitch; a wider range of pitch excursions; a slower, more repetitive tempo; and an increased emphatic intensity (Bettes, 1988; Fernald & Simon, 1984; Grieser & Kuhl, 1988; Papoušek, Papoušek, & Symmes, 1991; Parker-Price, Cooper, Culp, & Culp, 1992; Shute, 1987). The universality of these features for ID speech to prelingual infants has been strengthened as researchers replicate the findings in cross-language and cross-cultural studies (Fernald & Simon, 1984; Grieser & Kuhl, 1988; Fernald et al., 1989; M. Papoušek, 1994)². Fernald et al. (1989),

Ratner and Pye's (1984) observations of maternal ID speech to three Guatemalan children indicated that either these mothers did not vary their average pitch level from AA interactions to AI interactions, or as in one case, a mother significantly lowered her average pitch when interacting with her child.

compared the A-I speech to A-A speech of mothers and fathers of infants between the ages of 10 and fourteen months. An equal number of participants natively spoke one of six different languages.

In French, Italian, German, Japanese, and British and American English, both mothers and fathers spoke with higher fundamental frequency (pitch), greater f_0 -variability (pitch variability), shorter utterances, and longer pauses in speech addressed to preverbal infants than in speech addressed to adults (p.491).

This study will expand the literature to include an investigation of the pitch (fundamental frequency (f_0)) variability in ID speech in the underrepresented population of the Deaf and the hard of hearing, a population consisting of 2 million people in the United States alone (Groce, 1985; Marschark, 1993). Fundamental frequency (f_0) is the conventional metric used to quantify "the lowest and most intense of the voice frequencies" (Warren-Leubecker & Bohannon, 1984, p.1381). Essentially, f_0 is an index or a physical correlate of perceived pitch, but as Shute (1987) noted, a linear relationship does not exist between the two.

Studies of Motherese in Sign Languages

Until recently, studies of motherese have involved participants who have functional auditory processing and are using a vocal language; thus these studies have ignored the Deaf, the hard of hearing, and/or individuals whose

The average age of the limited sample was 2;2, and all three children were demonstrating some level of expressive language.

primary language is Sign. Reilly and Bellugi (1990), began to address this bias in the motherese literature with their study of the functional use of facial expressions by 15 deaf parents with their deaf toddlers.

In American Sign Language (ASL), facial expressions can efficiently communicate both affective meaning and grammatical information (Klima & Bellugi, 1979). Klima & Bellugi write:

ASL economizes by doing without the kinds of grammatical morphemes that English uses; ASL has special ways of compacting linguistic information which are very different from those of a spoken language like English. (1) The structured use of space, (2) the superimposed modulations of the movement of signs, and (3) the simultaneous use of facial expression for grammatical purposes permit compacting of information without significantly increasing production time (p. 194).

Reilly and Bellugi (1990) explored whether parents signing to their infants would decompress the linguistic information in ASL in order to effectively use the form of facial expressions to accomplish one of two competing functions, either affective communication or grammatical usage. Their findings demonstrated that before the child was two years old, both parents subordinated the morphological function of facial expressions and reserved those modalities almost exclusively to convey affective messages. It was not until after the age of two that the child's parents used grammatical facial expressions to communicate linguistic information to him or her. Seemingly, for the infant's first two years of life, facial expressions in ID ASL communicate affect in A-I interactions, and thereafter,

those forms serve a multi-functional role by conveying both grammatical and affective information.

This chronological progression from the simple structure of manual sign to the more complex incorporation of the signed morphemes like facial expressions possibly facilitates language acquisition. Still, exclusion of the grammatical use of facial expressions until the third year may also achieve the function of increased infant attention. Reilly and Bellugi (1990) noted that the morphological facial expressions necessary to imply the syntactical models of the study, mainly WH- questions (e.g. Where? What? How? etc.), involve furrowed eye brows and a head tilted slightly forward. The investigators concluded that these facial signals, if used by a parent, could effectively communicate an expression of anger or puzzlement, or even a general termination cue to the infant and that obviously, a parent's use of such expressions could quickly undermine the effectiveness of positive facial expressions in regards to gaining and maintaining an infant's attention.

Masataka (1992) observed eight deaf mothers using their first language, Japanese Sign Language (JSL), in interactions with their profoundly deaf infants and with other adults who used JSL. Masataka characterized deaf mothers' ID JSL as having features such as a slower tempo, more repetition, and larger exaggerated movements than AD JSL. Analogous to attributes of ID speech as being evocative of infant attention, Masataka suggests that the features of signed motherese seemed to "evoke more robust responses (visual) from the infant" (Masataka, 1992, p. 459). But he does not limit discussion of the possible

functions of ID JSL to attention bids; he continues the analogy to ID speech to postulate that features of ID JSL also facilitate language acquisition and communicate affect to infants.

As shown above, Reilly and Bellugi (1990) and Masataka (1992) are among the few to have expanded the motherese literature to include the Deaf population. This study endeavored to enrich this important line of motherese research. However, unlike the previous two studies which investigated the features of Signed motherese, this research was conducted as an extension of the investigations of classic acoustic features of ID speech, specifically the mean fundamental frequency (f_0) as well as f_0 -variability.

This research included analyses of maternal vocalizations obtained from dyadic interactions in which deafness affects the mother, her infant, or both the mother and her infant. Traditionally, vocal data for acoustical analyses of ID speech are generated from two conditions in which mothers are recorded speaking to an adult and to an infant. The speech patterns from the conditions are then compared. Since data from a mother-adult condition were unavailable, this study analyzed the vocalizations of hearing mothers with their hearing children and used these data as a source for comparison. Reliability in our measures of f_0 was demonstrated by replication of previous findings from other research conducted in hearing populations.

The Impact of Deafness On Early Development

The Deaf are not silent (Sacks, 1989), and therefore, a Deaf mother may communicate affective engagement or linguistic information to her infant through

vocalizations as well as through other modalities like visual-gestural, touch, and/or kinesthetics. The current study analyzed similarities and differences between fundamental frequencies used by Deaf mothers with their deaf infants, Deaf mothers with their hearing infants, hearing mothers with their deaf infants, and hearing mothers with their hearing infants. Such comparisons have significant implications for our understanding of how deafness affects communication in mother-infant dyads and for our understanding of the adjustments parents make to compensate for either their infant's deafness or their own deafness. Meadow-Orlans, MacTurk, Spencer, & Koester (1991) stress that as diagnostic procedures for identifying deafness improve, there is an increasing need for research on the "developmental impact of early hearing loss" (p. 1).

This study analyzed data collected as part of a longitudinal research project conducted at Gallaudet University (Meadows-Orlans, et. al., 1991; MacTurk, Meadow-Orlans, Koester, & Spencer, 1993). It was designed to coincide with the project's original goal of investigating the impact of early hearing loss on mother-infant interactions. This study's findings also serve as an exploration of the linguistic, attentional, and social/affective functional explanations of motherese (discussed briefly above and more extensively below). Lastly these results could provide additional clues concerning the universality of the prosodic features of motherese, by incorporating data from both Deaf and hearing mothers in a cross-cultural comparison of cultures using manual versus vocal languages. The results of this study will hopefully be

beneficial both to researchers of human development and to parents and professionals concerned with early intervention efforts on behalf of deaf children or children of Deaf parents.

Quantifying Pitch

Over thirty years ago, Ferguson (1964, as cited in Grieser & Kuhl, 1988) reported his subjective observations of the elevated and variable pitch in ID speech in adults who spoke one of six different languages. His work instigated a long succession of cross-cultural studies that have investigated how dimensions of vocal pitch distinguish ID speech from AD speech. Remick (1971, as cited in Andersen, 1977 Garnica, 1977, and Remick, 1976) was the first in this series of studies to attempt to quantify and describe ID pitch as average (median) fundamental frequency and as f_0 range. She observed the speech of eight mothers interacting with either their infants (16 to 30 months old) or the experimenter. Then she ran a spectrographic analyses on sentence samples from both interaction sessions. She concluded that ID speech to a younger child was more elevated and had a greater range than ID speech to an older child, and that ID speech had higher median f_0 and range than AA speech.

Garnica (1977) suggested several procedural flaws in Remick's design including unrepresentative sampling of sentences and ambiguous spectrograph analyses procedures. Therefore, Garnica designed a study which would address those issues and which tested similar hypotheses:

Hypothesis I: The use of prosodic and paralinguistic features in adult speech directed to young children differs systematically from the presence

and distribution of these features in adult-adult speech.

Hypothesis II: Differences in the present use of these features vary as a function of the relative age of the child addressee. Generally the older the child, the closer the usage pattern of these features will approach the pattern in adult-adult speech (p.67).

Garnica recorded the speech of 24 mothers during A-A and A-I interaction sessions. Twelve mothers had children of approximately five years of age, and twelve mothers had toddlers of about 2 years of age.

Garnica sampled 14 sentences from three conditions (picture generated narrative, short story reading, and puzzle solving instructions) in each interaction session. Then the sentences were converted to spectrograms from which the following fundamental frequency data were recorded: 1) the f_0 of the beginning, peak, and end point of the syllable nucleus in each utterance; and 2) the location of the peak within the syllable nucleus. Intra-observer reliability was assessed for the measurements of f_0 and was deemed "acceptable." The correlation of remeasurements of f_0 with the initial measurements was +0.97.

Garnica calculated the mean fundamental frequency for age and session from the three data points measured along the syllable nuclei. The results showed that the mean fundamental frequency was significantly higher for speech to a two-year-old than for speech to an adult; however, the mean f_0 was not significantly different for speech to a five-year-old and speech to an adult.

The fundamental frequency ranges were calculated by subtracting the lowest frequency from the highest frequency produced in a session. The ranges

were larger for speech to two-year-olds (highly significant) and speech to five-year-olds (significant) than for speech to adults. "In speech to the two-year-old listeners the low end of the frequency range is about the same as it is in the adult listener session. The range is expanded greatly at the higher frequency end" (Garnica, 1977, p.76).

As discussed above, fundamental frequency is merely an index of perceived pitch, and a linear relationship does not exist between the two (Fernald et al., 1989; Garnica, 1977; Grieser & Kuhl, 1988; Shute, 1987). A change in frequency from 300 Hz to 400 Hz is perceived as a greater increase in pitch than a change from 800 to 900 Hz. To address this issue, fundamental frequency data are often converted into the semitones of the equally tempered musical scale which is logarithmically related to f_0 and more closely approximates pitch perception. Researchers (e.g. Garnica, 1977) also convert f_0 data to semitones for graphical and narrative descriptions because the musical scale is more accessible to readers. Finally, conversion to semitones is especially appropriate for cross-language and inter-gender comparisons where pitch ranges will vary with the individual differences of the participants as well as with the ID and AD speech (Grieser & Kuhl, 1988; Fernald et al., 1989; M. Papoušek, et al., 1991).

Since Garnica's study, many studies have been conducted in efforts to understand better the continuous nature of fundamental frequency. In the past twenty years, researchers have used a variety of dynamic and summary measurements of vocal fundamental frequency (Katz et al., 1996). Dynamic

measurements attempt to capture the continuous nature of fundamental frequency while summary measurements synthesize data points into a descriptive statistic like a mean, standard deviation of the mean, median, mode, or range.

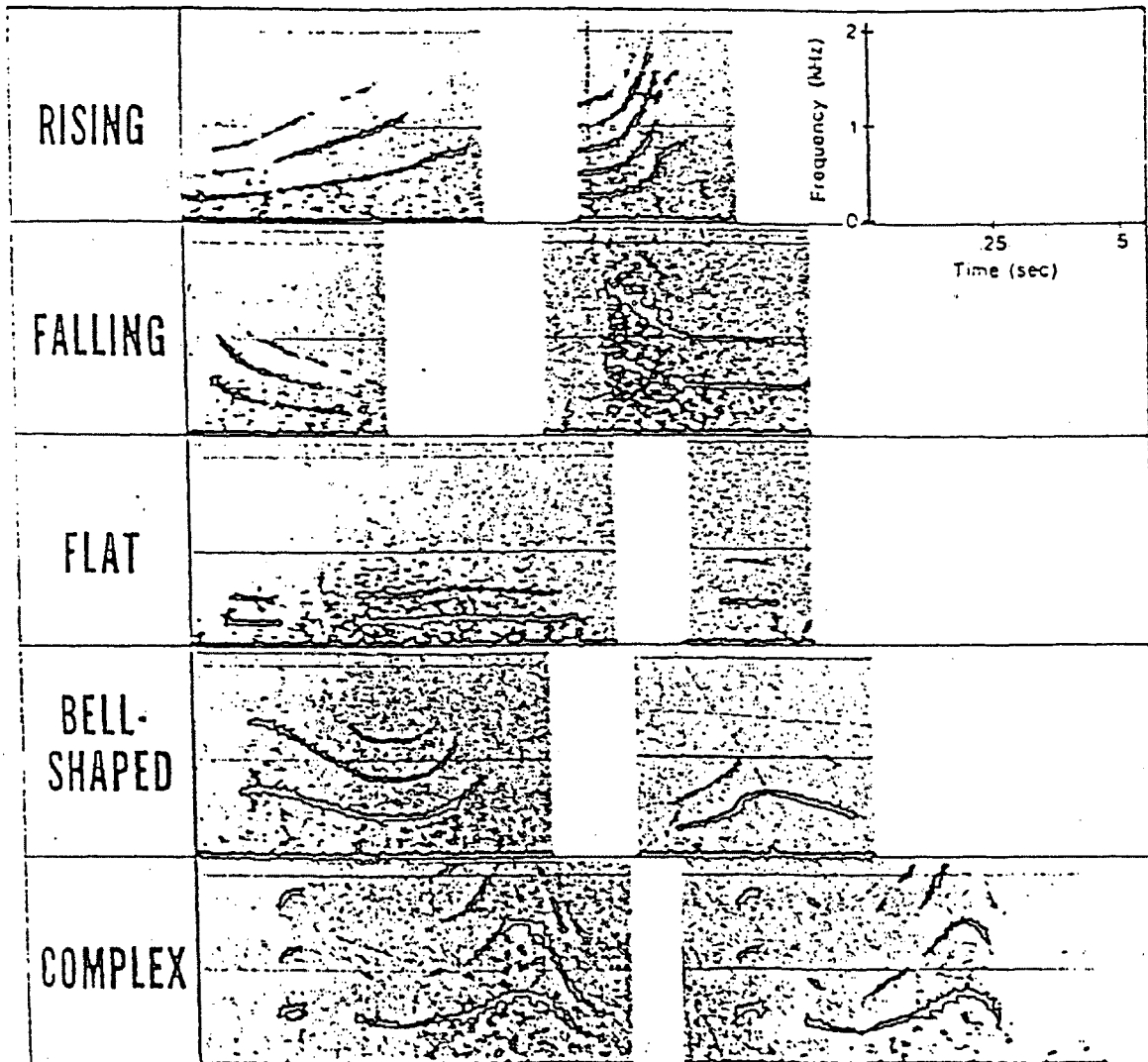
Dynamic measurements

In 1982, Stern, Spieker, and MacKain identified five contour shapes common to the f_0 curves in ID speech: the "sinusoidal" contour (up-down-up or down-up-down), the "bell shape" contour, the "bell right" contour (slight upward rise with a large downward turn), the "rising" contour, and the "falling" contour. Fernald and Simon (1984) identified similar contours except that they described "sinusoidal" contours as "complex" and included "u-shaped" contours but not "bell right" contours. Grieser & Kuhl (1988) excluded the "u-shaped" and "bell right" category from their analyses but added a "flat" contour shape which is similar to the "level" contour used by M. Papoušek et al. (1991). (See Figure 1 for examples of different contour shapes as illustrated by the above authors' data.)

The majority of these studies have been investigating these types of fundamental frequency contours in order to determine their possible prosodic and paralinguistic functions as well as the extent to which they are a universal occurrence in ID speech. Consider the following robust findings: a rising contour has been interpreted as having an initiating function in both American-English and Mandarin Chinese ID speech; the bell-shaped contour has been highly correlated with maintaining infant interactions and showing approval; and a

slowly falling contour has been associated with comforting a distressed infant (for a review, see M. Papoušek, 1994). Results, such as these, are products of complicated experimental design and analyses and were beyond the limits of the current study's archival data set.

Figure 1. "Spectrographic displays of the five prototypic intonation contours observed in Chinese Mandarin motherese. The lowest bar represents the fundamental frequency (f_0) and the parallel bars above it represent harmonics of the fundamental" (Grieser & Kuhl, 1988, p. 17).



Most recently, Katz et al. (1996) employed quantitative modeling to describe ID f_0 contour shapes using various mathematical functions (e.g. exponential, linear, power, sinusoidal, decay, transfer, etc.). Katz et al. were also successful in demonstrating not only a correlation between dynamic features of f_0 and contextual usage, but also between summary measurements (mean f_0 and f_0 variability/S.D.) and pragmatic categories like communicating approval, comfort and social bids.

Summary measurements

In the motherese literature, the types of summary measurements used to describe ID speech have varied more in the past twenty years than the different categories of f_0 contours. The following measures have been used to distinguish ID speech from AD speech and to make cross-language, cross-cultural, parental experience, and gender comparisons: mean fundamental frequency (Fernald & Simon, 1984, Fernald et al., 1989; Garnica, 1977, 1978; Grieser & Kuhl, 1988; Jacobson, Boersma, Fields, & Olson, 1983; Katz, et al. 1996; Papoušek et al., 1991; Parker-Price et al., 1992; Ratner & Pye, 1984); median f_0 (Remick, 1976); maximum and minimum f_0 frequencies (Fernald & Mazzie, 1991; Garnica, 1977; Papoušek et al., 1991; Stern, Spieker, Barnett, & MacKain, 1983); f_0 mode (Warren-Leubecker & Bohannon, 1984); F_0 range (Fernald & Mazzie, 1989; Fernald & Simon, 1984; Fernald et al., 1989; Garnica, 1977, 1978; Papoušek et al., 1991; Parker-Price et al., 1992; Ratner & Pye, 1984; Remick, 1976; Stern et al., 1983; Warren-Leubecker & Bohannon, 1984); and standard deviation of the

mean of f_0 (Fernald & Mazzie, 1991; Jacobson et al., 1983; Katz et al., 1996).

Besides varied use of different summary measurements, some researchers have used the hertz parameter to measure the f_0 while some researchers convert their data into semitones. Also depending on the study, the measures can be summarizing the f_0 of a session, a time unit, a syllable, an utterance, or a sentence. These inconsistencies in the research analyses have made inter-study comparisons difficult.

The current research used the following summary measurements to quantify the f_0 curve: 1) the mean f_0 for each utterance in hertz and semitones, 2) the standard deviations of each group's mean f_0 , and 3) the range of f_0 for each utterance in hertz and semitones. These measures summarized the pitch of each utterance. An utterance was defined acoustically rather than linguistically, as a section of vocalization bounded by pauses greater than 300 msec. (see Fernald et al., 1989).

Functional Explanations of Motherese

Grieser & Kuhl (1988) stated that "The acoustic features that are most salient are likely to be the ones that are 'universal' in maternal speech to infants across diverse languages and may well serve a common purpose" (p.20). Several "common purposes" or functions of the acoustic qualities of ID speech have been hypothesized, and these functions have guided the research of the melodic quality of ID speech. Grieser & Kuhl (1988) identified three main functions of motherese which they termed linguistic, attentional, and social/affective explanations:

The *linguistic explanation* is that pitch contour serves to mark major linguistic boundaries and thus to 'parse' speech, and that the expanded pitch contours that occur in motherese make these linguistic boundaries even more noticeable, thus 'instructing' infants about language. The *attentional explanation* argues that the overall higher pitch used in motherese as well as the dramatic expansions in the pitch contour of the voice are perceptually distinctive and salient; they serve to highlight acoustically the speech that is addressed to the infant as opposed to someone else, and this promotes infant attention as well as communicative 'turn-taking' by the infant. The *social/affective explanation* argues that the mother's use of a higher pitch and expanded pitch contours signals positive affect for the baby and correlates with other positive things she does when interacting with the infant. Infants may initially (or eventually) recognize these signals as positive (pp. 13-14).

While it will be clearer to discuss these three explanations as separate issues, their relationships to one another should not be forgotten. For example, affective exchange is necessary to establish the intense mother-infant social interaction (Papoušek & Papoušek, 1990) which is crucial to language acquisition (Pepperberg, 1993; Pepperberg & Neopolitan, 1988; Pepperberg & Schinke-Llano, 1991), and reciprocally language acquisition furthers socio-emotional and cognitive growth (Snow, 1977). Clearly the establishment and maintenance of an infant's attention is critical to maternal affective communication and lingual didactics.

The linguistic function of motherese

The linguistic function of ID speech would be best supported by longitudinal studies in which the acoustic features are the independent variable and language acquisition is the dependent variable; a review of the literature has revealed no such study to date. Still, Karzon (1985, as cited in Grieser & Kuhl, 1988 and as cited in Papoušek et al., 1991) has shown that infants discriminate more reliably between two nonsense words differing only by one syllable when the words are spoken with higher f_0 and expanded f_0 contours, both characteristic features of ID speech. Karzon demonstrated how the acoustic elements of ID speech communicated important linguistic information to the infants. Indeed, in keeping with Garnica's definition (as described above), the higher f_0 and expanded contours in Karzon's study constituted a form of prosody.

Kuhl and colleagues (1997) have demonstrated that speech directed at infants in the United States, Russia, and Sweden contained phonetic units which were acoustically different when compared to those found in adult directed speech. Specifically, the three "point" vowels, /i/, /a/, and /u/, along with the acoustic space surrounding them form larger "vowel triangles" in ID speech than they do in AD speech. The vowel and consonant articulations of AD speech which are "...poorly specified" and often "...undershoot their intended targets, resulting in an overlap in the acoustic cues specifying distinct categories" (Kuhl et al., 1997, p. 684) are in a sense 'cleaned up' for infants who are learning to hear (Stager & Werker, 1997) and then use those distinct categories (Kuhl et. al., 1997).

Intuitive parenting (Papoušek & Papoušek, 1987; Papoušek & Bornstein, 1992) predicts that a parent will automatically, but not necessarily intentionally, make all kinds of behavioral adjustments (not just those of motherese) to facilitate a social context between the parent and the infant in which language lessons didactically occur. Papoušek and Bornstein (1992) described a longitudinal observation of 17 German mothers interacting with their infants. The imitative models which mothers provided for the infant were well-matched with the types of vocalizations the infant was anatomically prepared to produce. So for example, when the infant could regulate intermittent breathing, the parent provided that child with imitative models of canonical babbling such as "ba ba ba" or "da da da" (which requires controlled intermittent breathing).

To generalize the idea of intuitive parenting to the current study, it may be useful to examine how a deaf infant's vocalizations develop. Oller, Eilers, Bull, & Carney (1985) described the vocal development in one deaf girl between the ages of 8-13 months. When compared with eleven hearing children, this girl employed fewer fully resonant vocalizations, which are adult-like vocal sounds involving more high frequency energies. Instead she produced quasi-resonant sounds involving many low frequencies. If a parent intuitively adjusts his/her behavior, then one would expect that a parent of a deaf child would use lower frequencies when providing imitative models during social interactions. So, the mothers of deaf infants who participated in Gaulladet's longitudinal study may be expected to use a lower mean f_0 than mothers of hearing infants.

The attentional function of motherese

The attentional explanation has been supported by several investigations which illustrated that infants prefer A-I conversation over A-A conversation (Cooper & Aslin, 1990; Fernald, 1985; Fernald & Kuhl, 1987). Cooper and Aslin (1990) demonstrated this preference in infants as early as two days after birth, and Fernald and Kuhl (1987) established that fundamental frequency patterns were a more salient prosodic feature for 4-month-old infants than duration (tempo) or amplitude (intensity). By adjusting ID speech patterns to match the preferential predispositions of infants, parents maximize the effectiveness of their vocal attention bids.

The social/affective function of motherese

The social/affective function of ID speech, in which "...melodic contours may in fact function as potent mediators of affective communication (Lewis, 1936) and signal the speaker's overall affective engagement," (as cited in M. Papoušek et al., 1991, p.46), is best evidenced by studies such as that conducted by M. Papoušek et al. (1991). These researchers were able to pair affective meaning with specific melodic contour types by classifying the shapes of maternal speech contours in mother-infant interactions, characterizing the emotional tone of the interaction, and identifying which contour shapes occurred most often within the various emotional contexts.

Bettes (1988) demonstrated more through omission how acoustic elements of ID speech can fulfill the function of affective engagement. She observed the ID speech of 36 mothers to their 3- to 4-month-old infants using

temporal summary measurements and dynamic contour measurements, and then she administered the Beck Depression Inventory to all of the mothers in an effort to determine maternal depression. Her results suggested that "Depressed mothers, in general, failed to impose structure on their vocal behavior" (Bettes, 1988, p.1095). Indeed, the depressed mothers took longer to respond to their children and were six times more likely to respond with a nonexaggerated manner than the nondepressed mothers. Parker-Price et al. (1992) reported similar findings from their comparison of adult mothers' and teenage mothers' use of ID speech. Teenage mothers demonstrated more f_0 variability (although it was not clear how they defined variability) in ID speech than AD speech; however, adult mothers varied the f_0 in their ID speech significantly more than did the teenage mothers.

Summary and Purpose of Study

The main hypotheses of the current study reflect in part the three proposed functions of ID speech: linguistic, attentional, and social/affective. Cultural theory and the theory of intuitive parenting guided predictions made for each group of mother-infant dyads.

Deaf mother/deaf infant

It was anticipated that Deaf mothers convey linguistic information to her deaf child through a modified version of ASL (Signed motherese), although it was not possible to test this directly in this investigation. Were this to be the case, the forms of higher means of f_0 and larger f_0 standard deviations and ranges would not be the primary adaptations employed to achieve the proposed

linguistic function of motherese. Also for a Deaf-deaf dyad, acoustic elements could not accomplish the suggested attentional function. Instead a behavioral form requiring no audition (e.g. touch and facial expressions) would best achieve the attentional function.

Formulating a prediction as to whether the social-affective function would be reflected by a higher mean f_0 with larger f_0 S.D. and ranges, was more difficult. Such vocalizations may occur almost reflexively in concert with physiological mood states (Owren, Bachorowski, & Sly, 1995). Therefore, a Deaf mother's ID speech to her deaf child should only utilize the forms of higher mean f_0 with larger f_0 S.D. and ranges to achieve the social-affective function, but again a Deaf mother is so accustomed to using other modalities that even then such acoustic variations may not be detectable.

Hearing mother/deaf infant

It was anticipated that the hearing mother who is learning to sign would also convey some linguistic information to her deaf child through a simplistic version of ASL, but that this would more likely be a reflection of her own level of ASL proficiency than an adaptation of ASL for specific use with an infant. A hearing mother could also attempt to communicate linguistic information to the infant with a vocal language especially if this is consistent with her belief that the infant is capable of acquiring a vocal language. In which case, the typical forms of higher means of f_0 with larger f_0 standard deviations and ranges would be observed in hearing mothers' ID speech even with a deaf child, possibly in an attempt to achieve the proposed linguistic function of motherese. However,

because deaf infants may use lower f_0 in their vocalizations (Oller et al., 1985), hearing mothers might intuitively match this pitch level when providing imitative models.

As described for the Deaf-deaf dyad, acoustic elements would be less effective for accomplishing the suggested attentional function in these hearing-mother-deaf-infant interactions as well. Some previous analyses (Brooks, Gage, Koester, Traci, & Wetterling, 1995; Koester, 1995; Koester, Karkowski, & Traci, 1998) have shown that by the ninth month of face-to-face interaction with her deaf infant, a hearing mother will attempt to achieve infant-attention differently than will a hearing mother with a hearing infant in terms of using vocal, visual, and tactile modalities.

It was proposed that the social-affective function would most likely be reflected by a higher mean f_0 with larger f_0 S.D. and ranges. Therefore, a hearing mother's ID speech to her deaf child would exemplify the forms of higher mean f_0 with larger f_0 S.D. and ranges to achieve the linguistic function. The social-affective functions would most likely be accomplished by higher mean f_0 with larger f_0 S.D. and ranges. And as with the Deaf mother, communicative modalities other than vocal would probably be used to establish infant attention.

Deaf mother/hearing infant

In terms of communicating linguistic information, the three summary measurements of fundamental frequency for the dyad involving a Deaf mother with a hearing infant were predicted to be most similar to those of the Deaf mother with the deaf infant dyad. Still, the Deaf mother with a hearing infant

would be more likely to bid for infant attention using a f_0 mean with f_0 S.D. and ranges that would be higher than those used by Deaf mothers with deaf infants, especially since these are such salient acoustic stimuli for hearing infants (Cooper & Aslin, 1990; Fernald, 1985; Fernald & Kuhl, 1987). One might argue that without the auditory feedback loop, Deaf mothers would be unable to inflect their voices appropriately; however, the necessity of this capability seems counterintuitive to the arguments that it is the increased attention of the infant that is eliciting this high pitched pattern. Also such an argument implies a complete lack of volitional vocal control which would be inaccurate when describing members of the Deaf community who have received extensive speech therapy and coaching.

The social-affective function could again be achieved with the variety of modalities in a Deaf mother's communicative repertoire. The Deaf mother with a hearing infant probably uses the vocal channels more than the Deaf mother with a deaf infant. This could be another example of intuitive parenting, of matching the infant's abilities and predispositions.

Therefore, it was anticipated that a Deaf mother with a hearing infant would use higher f_0 with larger f_0 S.D. and ranges to a greater extent than a Deaf mother with a deaf infant. Since all three functions can hypothetically be accomplished by utilizing these forms to communicate with a hearing infant, the only limitation of their use will be the Deaf mother's communicative preferences and verbal capabilities. Such limitations will probably result in the following: 1) lower mean f_0 with smaller f_0 S.D. and ranges than found in dyads with hearing

mothers and 2) higher mean f_0 with larger f_0 S.D. and ranges than observed in Deaf mothers with deaf infants.

Hearing mother/hearing infant

Hearing mothers with hearing infants are characteristic of the participants in most motherese studies of ID speech. They were considered the group most likely to produce higher f_0 with larger f_0 S.D. and ranges in order to communicate linguistic information, affect, and social bids. They were also thought to be most likely to display the highest mean f_0 and the largest f_0 S.D. and ranges of any of the dyads proposed for this investigation.

Summary

In summary, it was predicted that results of the proposed study would reflect elevated mean f_0 and expanded f_0 S.D. and ranges to the extent that the specific forms of higher pitch and wider contours are customary and appropriate to accomplish the linguistic, attentional, and social/affective functions in a mother-infant social interaction. It was anticipated that the use of acoustic elements in maternal speech directed to infants would differ systematically with the hearing status of the infant and the mother.

Hypotheses

- A. Deaf mothers with deaf infants will have the lowest mean f_0 and the smallest f_0 S.D. and ranges of all mothers in the four groups of the current study.
- B. Hearing mothers with hearing infants will have the highest mean f_0 and the largest f_0 S.D. and ranges of all mothers in the four groups

of the current study.

- C. Hearing mothers of deaf infants will have a higher mean f_0 and larger f_0 S.D. and ranges than Deaf mothers with deaf infants and Deaf mothers with hearing infants, but these mothers will have a lower f_0 and smaller f_0 S.D. and ranges than the hearing mothers with hearing infants of the current study.
- D. Deaf mothers of hearing infants will have a higher mean f_0 and larger f_0 S.D. and ranges than Deaf mothers with deaf infants, but these mothers will have a lower f_0 and smaller f_0 S.D. and ranges than the hearing mothers with deaf infants and the hearing mothers with hearing infants of the current study.

Method

The participants were selected from a sample of mothers and infants who were involved in a longitudinal study designed to "...provide basic developmental information to behavioral scientists, and to provide a basis for informed intervention to parents and educators responsible for the early care of hearing-impaired infants" (Meadow-Orlans et al., 1991, p.1). Mother-infant interactions involving deaf and hearing infants with their Deaf or hearing mothers were recorded on videotapes for later analyses to determine possible effects deafness may have on early cognitive, social and communicative development (MacTurk, et al., 1993). Observations were ideally recorded when the infants were six-, nine-, twelve-, and eighteen-months-old, though late diagnoses of deafness resulted in incomplete samples for the six month observation session. Extensive home interviews were conducted when the infants were fifteen months old to determine medical background and levels of family stress and support.

Observations took place in university laboratory facilities designed for unobtrusive videotaping of activities such as dyadic interactions, mastery motivation tasks, free play, and attachment relationships. This study used these videotapes to investigate f_0 variability in ID speech even though the videotapes were part of an archival data set which was not specifically collected for acoustical analyses.

Participants

Participants of the longitudinal study were predominantly from Caucasian, middle class families (as determined by the Hollingshead Two-Factor Index of

Social Position; see Meadow-Orlans, et al., 1991), with both parents present in the home. The mean age of participating mothers included in the current study of ID speech was 32.15 years (SD 4.10), and the minimum and maximum ages were 23 and 40 years. All of the Deaf parents were recruited at Gallaudet University, the principal site for the longitudinal study. As a result, the Deaf mothers in this sample tended to identify with the Deaf American Culture (see Stokoe, 1989, for a review) and to use American Sign Language (ASL) with their infants. Groups in the original sample were matched based on educational level of the mothers.

Because the participating infants were identified as deaf by six or nine months of age, a diagnosis which usually is not made, on average, until two years of age (Batshaw & Perret, 1992), the sample of infants in the study represented a small minority of the Deaf population. Infants were drawn from five different metropolitan populations: Washington, D.C. (Gallaudet University); Pittsburgh, PA (University of Pittsburgh); Dallas, TX (University of Texas); and Boston, MA (University of Massachusetts). In 1988, research affiliates at each site began to contact hospitals, audiology clinics, and early intervention programs in their areas seeking referrals of families with deaf infants. Any infants with additional visual impairments or motor delays were excluded from participation in the study.

The mothers and infants of families who agreed to participate were grouped according to hearing status as follows:

Group 1) Deaf Infants/Deaf Mothers (DIDP)

Group 2) Deaf Infants/Hearing Mothers (DIHP)

Group 3) Hearing Infants/Deaf Mothers (HIDP)

Group 4) Hearing Infants/Hearing Mothers (HIHP)

Dyads could be included in the current study of ID speech if the sound quality of the videotape was sufficient during Episodes I and III (see below) and if during those episodes, the mother vocalized frequently enough so that a minimum of 19 utterances could be recorded as wavefiles to be used in the analyses. The latter restriction especially limited which dyads from the DIDP and the HIDP Groups could be included in this study; after transcribing randomly selected videotapes from these groups, 12 dyads from each group were determined to have sufficient vocal data (amount and quality) to be included in the analysis. It will be important to keep in mind that, for this study, the analyses and results reflect data collected from subsamples of the DIDP and possibly the HIDP groups, and that these data were generated from mothers who vocalized sufficiently during episodes I and III and were satisfactorily recorded doing so. The number of dyads in the DIHP (n=14) and HIHP (n=15) groups were limited to being one-third larger than the minimum number of the other two groups to ensure robust analyses of variance.

Special characteristics of Deaf participants. Degree of hearing loss for the deaf infants was determined by trained audiologists using the following threshold criteria: mild (25-40 dB); moderate (41-55 dB); moderate-severe (56-70 dB); severe (71-90 dB); and profound (91 and > dB). Most of the deaf infants included

in the current study of ID speech had a severe or profound hearing loss (n= 21) while a few had a moderate-severe hearing loss (n=3). This information was missing for one infant from the DIDP group. The infants' hearing loss was matched between groups 1 and 2. The infant with missing information on hearing level was matched to an infant with a severe hearing loss.

Hearing aids. The initiation of hearing aid use was generally very early for a deaf infant with a hearing mother (mean age of 6.95 months for first fitting), while deaf infants with Deaf mothers rarely had hearing aids since they were expected to be learning ASL as their first language. The degree to which a fitted hearing aid was actually utilized by deaf infants with hearing mothers also varied considerably with the infant's acceptance or resistance to it. Indeed, some infants who normally wore the hearing aids may have protested on the day of observation, resulting in the mother removing them for the videotaping session. Therefore, variability of hearing aid use may have occurred both within and between groups. Still, it can be asserted that at the time of the observations, the majority of deaf infants with hearing mothers were wearing hearing aids during most of their waking hours, while the deaf infants with Deaf parents had typically not been fitted with hearing aids.

Early intervention. By age nine months, virtually all of the deaf infants with hearing parents were participating in some kind of early intervention program; the one exception was an infant who was on a waiting list but was admitted to a program soon after. The resources available to the participants represented a broad array of Deaf educational philosophies including home- and center-based

programs as well as auditory-verbal, oral, and total communication training.

These and other supports were provided by various sources like public or community agencies, universities, private therapists, and residential schools for the Deaf.

Procedure

Observational procedure. During the 9-month observations acoustically analyzed for the current study, each of the mother-infant pairs was videotaped during face-to-face interaction, as described below. For this purpose, the baby was placed in an infant seat on a table directly in front of and facing the mother. No toys or other objects were used during the observation period. The face-to-face interaction segments were structured according to the standard infancy research procedures for such observations, as follows:

Episode I, Normal Interaction: The mother was instructed to interact with her infant (while both were seated) just as she would normally do at home when she had a few minutes to spend with the baby.

[**Turn Away:** For transition to the Still-Face segment, the mother was asked to turn 90 degrees in her chair so that she was no longer 'face-to-face' with her infant. She was directed not to touch or vocalize to the infant during this time.]

Episode II, Still-Face: The mother was asked to face her infant again, but not to touch, speak, smile, communicate (for example, with ASL), or respond to him or her in any way. Since the purpose of the current study is to measure the f_0 of ID speech, no data were collected from this episode.

Episode III, Resumed Normal Interaction: The mother was instructed to resume normal interactions, as in the first episode (2 minutes).

Each face-to-face interaction session was videotaped from behind one-way mirrors using two cameras and a special effects generator to produce a split-screen image. Videotapes were then coded by using a remote-controlled videocassette recorder linked to a personal computer equipped with data-acquisition and recording programs.

For the current study of ID speech, observations of maternal vocalizations were harvested from Episodes I and III. All instances of vocalization suitable for the study during those Episodes were coded for further analysis; since Episode I lasted between 2 and 4 minutes and Episode III lasted approximately 2 minutes, the observation time varied somewhat between subjects. However, a one-way analysis of variance revealed no significant differences in observation times across the four groups ($F(3,49)=.5399, p=.66$). Table 1 describes the mean and standard deviation of observation times for each group along with other summary information describing the dyads used in the current study of ID speech.

Data reduction and analysis. A research assistant transcribed episodes I and III of the videorecordings for groups 1 and 3 (i.e. those with Deaf mothers) to approximate the number of maternal vocalizations available for analysis. It was then determined that 12 dyads from the DIDP and 12 from the HIDP groups included mothers who produced a sufficient number of utterances that were suitably recorded to be included in the analyses. Fourteen dyads were randomly selected from the DIHP group to the extent that infant hearing levels could be

matched to those in the DIDP group and the sound quality of the tapes was sufficient for analysis. Fifteen dyads were also randomly selected from the HIHP group excluding dyads whose sound recordings were of poor quality.

The audio recordings from the videotapes of these dyads were processed on Avisoft-SONAGRAPH Pro 2.5 acoustic analyzer interfaced with an IBM PC computer. Utterances were defined acoustically rather than linguistically, as a section of vocalization bounded by pauses greater than 300 msec. (see Fernald et al., 1989). A population of utterances was then generated for each participant. The utterances in these populations met the following selection criteria before being encoded into individual wavefiles: 1) they were relatively free of infant concomitant vocalizations and extraneous noise and 2) they were of adequate sound quality for acoustic analysis. Two coders were responsible for encoding all of the wavefiles for this study.

The minimum and maximum number of utterances saved as wavefiles for each mother was 19 for a Deaf mother with a deaf infant and 151 for a hearing mother with a deaf infant (see Table 1 for mean numbers of wavefiles). A random number table was then used to sample 15 wavefiles from each of the mothers' populations of utterances.

The randomly selected wavefiles were then converted into sound spectrograms for further acoustical analyses (see Figure 2). The following data points were recorded to a text file for statistical analyses:

1. The start and end times of the sonagrams were recorded to determine utterance length.

2. The highest and the lowest frequencies (Hz) were recorded as well as the start and end frequencies (Hz) of each sonagram.

Table 1

Descriptive Information of Participants by Group

Group	n	#of male infants	#of female infants	Mean Observation Time (sec.)	Mean Maternal Age (years)	Mean Number of Wavefiles
DI/DP ^a	12	8	4	313.0 (30.6) ^e	32.8 (3.3)	42.0 (21.8)
DI/HP ^b	14	4	10	333.6 (40.1)	32.2 (3.8)	94.4 (28.6)
HI/DP ^c	12	7	5	333.1 (27.2)	30.5 (5.4)	58.3 (27.9)
HI/HP ^d	15	5	10	336.3 (80.7)	32.8 (3.7)	76.1 (15.1)

^aDI/DP = Deaf Infant/Deaf Parent

^cHI/DP = Hearing Infant/Deaf Parent

^bDI/HP = Deaf Infant/Hearing Parent

^dHI/HP = Hearing Infant/Hearing Parent

^eNumbers in parentheses indicate standard deviations.

The sonagrams were then converted into a power spectrum which plots intensity in decibels along the y-axis and frequency in hertz along the X-axis (see Figure 2 for examples of a sound spectrogram/sonagram and a power spectrum). This representation was used to determine the mean frequency (Hz) for each utterance. These means were recorded with pencil and paper then were recorded into a data file for statistical analyses.

Whispers were identified as a type of vocalization that necessitated careful coding because the signal to noise ratio was such that visual identification of the above data points was very difficult. For this reason, after all wavefiles had been coded for the frequencies and times of interest, each one was played again. They were categorized as normal vocalizations, whispers,

almost whispers, and gasps. The latter three types of wavefiles were reanalyzed using multiple playbacks, multiple filter settings, and multiple codings. When a frequency was consistently (at least three times consecutively) identified as the frequency of interest (the highest or lowest frequency, or the starting or ending frequency), this value was recorded in the text file for that mother.

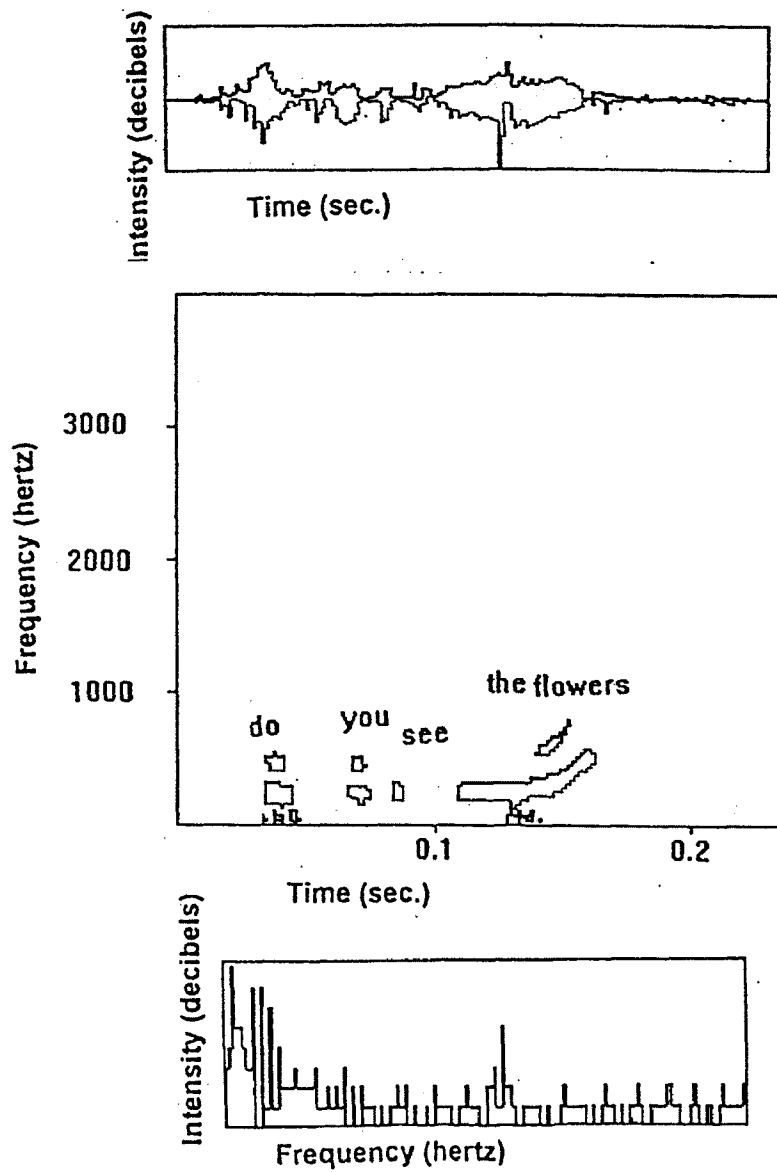
One coder was responsible for all of the frequency coding of the sound spectrograms. This coder was piloting procedures on these data in efforts to determine whether sound quality was sufficient for this level of acoustical analyses. This study indicated that indeed these data can be analyzed using such procedures, and summary measures of the maternal vocalizations' frequency can be described for this sample of mothers. Future analyses of this kind will involve at least two raters so that reliability measures can be calculated and reported. In addition, future coders will be blind to the hypotheses of the study as well as the defining qualities of the four groups. The coder for this study was not blind to either.

The following summary measurements were calculated for each utterance: 1) the mean fundamental frequency for each mother, 2) the standard deviation of the mean f_0 for each mother, 3) the range between the highest and lowest fundamental frequencies of each utterance (the f_0 -lowest subtracted from the f_0 -highest), and 4) the range between the starting and ending fundamental frequencies of each utterance (the f_0 -minimum subtracted from the f_0 -maximum). To promote meaningful comparison of similarities and differences in pitch across Deaf and hearing speakers, perhaps differing in f_0 -range, the raw scores for the

two f_0 ranges were converted into semitones as follows:

$$12\log_2[f_0\text{-maximum} / f_0\text{-minimum}]$$

Figure 2. A wavefile (intensity x time), a power spectrum (intensity x frequency), and a sound spectrogram/sonagram (frequency x time).



Results

The Mean F_0 and Its Standard Deviation

The mean fundamental frequencies of a participant's utterances were averaged resulting in one overall mean f_0 for each participant and one standard deviation (S.D.) describing the variability of frequency around the overall mean f_0 . The overall mean fundamental frequencies (see Figure 4) and the S.D.'s for those means were then averaged to compute four group mean f_0 's as well as four group means of the S.D.'s (see Table 2 for both the mean fundamental frequencies and the mean S.D.'s).

A one-way analysis of variance (ANOVA) revealed no significant differences in the mean fundamental frequency by group [$F(3,49)=2.67, p=.058$]; however, a 2x2 ANOVA (maternal hearing status x infant hearing status) was performed revealing a significant main effect of maternal hearing status on the overall mean f_0 [$F(1,49)=6.56, p<.05$]. The mean f_0 of hearing mothers was higher than that of Deaf mothers. No main effect was shown for infant hearing status and no interaction between maternal and infant hearing status was present.

A one-way analysis of variance (ANOVA) on the overall mean S.D.'s by group revealed significant differences [$F(3,49, p<.05)$]³, and a Tukey's Honestly

³ The Levene Test for Homogeneity of variances was significant ($p=.002$) for this ANOVA. No nonlinear transformation was conducted because given the degree of significance of the Levene test, such a transformation would not truncate the variance sufficiently to achieve homogeneity across groups. Nevertheless, results of the ANOVA are still reported here since the size of each group

Significant Difference (HSD) test revealed that hearing mothers with deaf infants had on average, more variability in the mean f_0 of their utterances than did Deaf mothers with deaf or hearing infants. A 2x2 ANOVA (maternal hearing status x infant hearing status) supported these findings with a significant main effect for maternal hearing status on the mean S.D. [$F(1,49)=10.49, p<.05$], but it revealed no main effect for infant hearing status and no interaction between maternal hearing status and infant hearing status.

The Mean Range (Lowest to Highest) in Hertz and Semitones

Two ranges were calculated for each utterance representing the differences between the highest and the lowest frequencies as measured in hertz and the differences between the highest and lowest frequencies after they were converted from hertz to semitones. Means were then calculated for each participant describing the average range in hertz and the average range in semitones. A mean range in hertz and mean range in semitones were then calculated for each group (see Table 2 and Figure 4). Two one-way ANOVA's revealed significant group effects for the mean range measured in hertz and the mean range represented in semitones [$F(3,49)=6.69, p<.05$ and $F(3,49)=17.82, p<.05$, respectively]. A Tukey's HSD test revealed that hearing mothers with hearing or deaf infants had on average, wider ranges measured in hertz than did Deaf mothers with deaf infants. However, a Tukey's HSD test comparing the mean ranges represented in semitones indicated that hearing mothers with deaf

was relatively the same and the ANOVA was presumed to be fairly robust to the heterogeneity of variances.

or hearing infants as well as Deaf mothers with hearing infants all used on average, wider ranges within the utterances of their ID speech. In addition, hearing mothers with hearing infants were shown to have on average, a wider range measured in semitones than did Deaf mothers with hearing infants.

A 2x2 ANOVA was performed to investigate the effects of maternal and infant hearing status on the mean range measured in hertz, and a similar ANOVA was performed investigating effects of the participants' hearing status on the mean range measured in semitones. The first ANOVA revealed that when the ranges were expressed in hertz, the group means were significantly affected by maternal hearing status only [$F(1,49)=25.77, p<.05$], and not by infant hearing status; there was no interaction. The second ANOVA showed that when the ranges were expressed in semitones, the group means were significantly affected by both maternal hearing status [$F(1,49)=25.77, p<.05$] and infant hearing status [$F(1,49)=15.32, p<.05$]. Again, there was not an interaction.

The Mean Range (Starting to Ending) in Hertz and Semitones

Two ranges were calculated for each utterance representing the differences between the starting and the ending frequencies as measured in hertz and as represented in semitones. Means were then calculated for each participant describing the average range in hertz and the average range in semitones. A mean range in hertz and mean range in semitones were then calculated for each group (see Table 2). Levene tests for homogeneity of variance revealed significant heterogeneity of variance ($p<.05$) in the four group means measured in hertz and the four group means represented in semitones.

A nonlinear transformation of the data truncated the variance in the means of both ranges so that Levene tests of means derived from the square roots of the data⁴ were no longer significant ($p > .05$).

The first one-way ANOVA revealed significant differences in the group means of the ranges between the starting and ending frequencies as measured in hertz [$F(3,49)=7.69, p < .05$]. A Tukey's HSD revealed that hearing mothers of deaf infants had a wider excursion from between their starting and ending frequencies measured in hertz than did Deaf mothers of deaf or hearing infants. Hearing mothers of hearing infants were also shown to have a wider range between starting and ending frequencies than did Deaf mothers of deaf infants. A second one-way ANOVA revealed that significant differences also existed between the group means of ranges represented in semitones [$F(3,49)=7.69, p < .05$]. A Tukey's HSD test demonstrated that hearing mothers of hearing or deaf infants had wider excursions between starting and ending frequencies as measured in semitones than did Deaf mothers with deaf infants.

The effects of maternal and infant hearing status on the means of ranges measured in hertz and represented in semitones were tested using 2x2 ANOVA's. Main effects for maternal hearing status were found on the group

4 For the mean range of the starting and ending frequencies measured in hertz, the raw data were nonlinearly transformed by taking their square roots. Means were then derived from the transformed data. For the mean range of the starting and ending frequencies represented in semitones, the raw data were first converted to a range represented in semitones. These ranges were then transformed by taking their square roots. Means were then derived from the transformed ranges.

means for the ranges expressed in hertz and ranges expressed in semitones [F(1,49)=19.26, $p < .05$ and [F(1,49)=20.09, $p < .05$], respectively. However, infant hearing status did not affect the group means expressed in hertz nor the group means expressed in semitones, and there were no significant interactions of maternal and hearing status affecting those means.

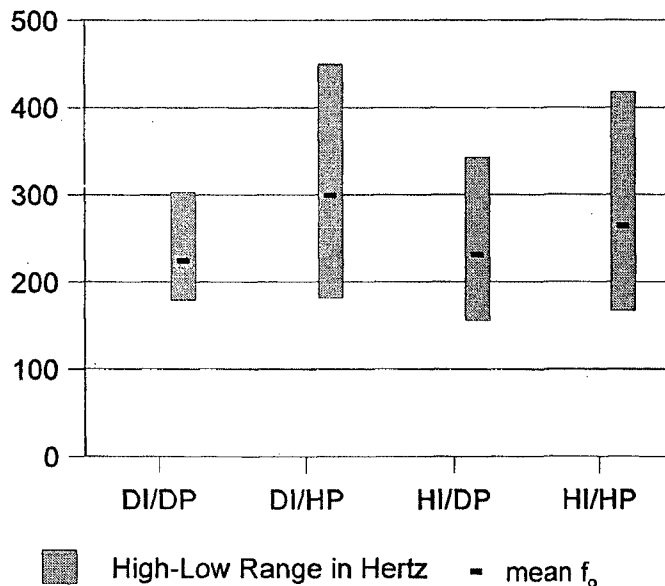
Table 2

Means of Summary Measurements of the Fundamental Frequency in ID Speech by Group

	DI/DP ^a (n=12)	DI/HP ^b (n=14)	HI/DP ^c (n=12)	HI/HP ^d (n=15)
Mean Fundamental Frequency	224.55 (31.61)	299.32 (78.77)	231.24 (86.55)	264.10 (88.80)
Mean Standard Deviation*	72.15 (23.56)	200.48 (145.46)	78.60 (65.08)	142.46 (130.44)
Mean Range (hi-lo) in hertz ***	123.87 (28.57)	268.01 (109.07)	187.33 (105.42)	250.97 (93.51)
Mean Range (hi-lo) in semitones****	9.05 (2.14)	14.57 (2.10)	13.13 (3.49)	16.04 (2.39)
Mean Range (start-end) in hertz***	64.15 (26.03)	158.48 (100.61)	91.41(54.56)	126.39 (56.81)
Mean Range (start-end) in semitones***	7.34 (2.51)	12.60 (3.79)	11.28 (5.33)	12.13 (4.63)

^aDI/DP = Deaf Infant/Deaf Parent ^cHI/DP = Hearing Infant/Deaf Parent
^bHI/DP = Deaf Infant/Hearing Parent ^dHI/HP = Hearing Infant/Hearing Parent
^eNumbers in parentheses indicate standard deviations.
 Group Effects: *p<.05; **p<.01; ***p<.001; ****p<.0001

Figure 4. Range between highest and lowest frequencies (hertz) and range between for each of the four groups.



Discussion

Results of the current study must be carefully considered in order to avoid possible misinterpretation. The archival data used in the present analyses were recorded in the late 1980s and early 1990s. Societal impacts, such as educational practices (e.g. bilingualism) and early intervention services, may have changed since that time, perhaps exposing more hearing mothers to American Sign Language (ASL) and Deaf American Culture (DAC) in ways that could alter interactional modality usage, including the vocal modality.

In addition to societal changes in the hearing world, changes in DAC along the lines of self-advocacy and empowerment⁵ may have affected the ways in which members of this culture now define themselves and in the number of “deaf” mothers who identify with DAC. Any of these changes could lead to a different proportion of Deaf mothers who, during standardized face-to-face interactions, vocalize sufficiently for acoustical analyses, and to variants of the spectral-temporal features structuring the utterances of the current analyses. Although many of the cross-cultural, -gender, and -age studies indicate that characteristics of ID speech would be robust to such changes, one should keep in mind that results of this study reflect the status and availability of ID speech for this particular cohort.

⁵ The Deaf President Now movement occurred in 1986 at Gallaudet University. Students boycotted classes, held sit-down protests, and insisted on the appointment of a Deaf president for the University. There were also demands that the University's board of regents for the University include a significant proportion of Deaf members.

Furthermore, the dyads with Deaf mothers who could provide vocal data for the analyses are a subset of the Deaf mothers participating in the Gallaudet Longitudinal study. Deaf mothers who do not normally vocalize or who were uncomfortable vocalizing under the scrutiny of the scientific observers (and therefore refrained from this during the observation) were excluded from the analyses of ID speech. Therefore, results reflect differences in vocalizations as they occurred during a standardized face-to-face interaction procedure. These differences describe the variation in summary measurements of the fundamental frequency of ID vocal utterances between Deaf mothers who vocalized during the videotaping with deaf infants, hearing mothers with deaf infants, Deaf mothers who vocalized during the videotaping with hearing infants, and hearing mothers with hearing infants.

Finally, the results of this study were affected by the quality of the sound recording on the videotapes. The archival data set was not collected with these types of analyses in mind, and the quality of the sound recordings was not optimal in some cases. Measurement error undoubtedly was compounded by this constraint in all four groups of dyads.

Characteristics of ID Speech in Deaf Mother-Deaf Infant Dyads

The results of the present study were predicted fairly well for the Deaf mothers with deaf infants. Overall, these mothers exhibited the prototypical features of ID speech to lesser degrees than did the other groups.

Although for Deaf Mothers of deaf infants there was only a trend toward having a significantly lower mean f_0 than the group with highest mean f_0 (DIHP),

Deaf mothers with deaf infants did have the lowest ranked mean f_0 of the four groups. This pattern concurs with one of the original hypotheses of this study. Also as hypothesized, Deaf mothers with deaf infants had the smallest f_0 S.D., or the least amount of variability among utterances of all four groups, and significantly less variability between utterances than hearing mothers with deaf infants. It also was predicted that the DIDP group would have narrower ranges between the highest and lowest frequencies within utterances and between the starting and ending frequencies within utterances when compared to the other groups. Results bore out this prediction. Deaf mothers with deaf infants had less of a range between the highest and lowest frequencies as measured in both hertz and semitones. Also, Deaf mothers of deaf infants had significantly narrower excursions between their starting and ending frequencies measured in hertz and represented in semitones than did hearing mothers of deaf or hearing infants.

These results argue strongly for the hypotheses generated for the DIDP group using the functional analysis outlined in the introduction of this paper. It is most likely that Deaf mothers have adequate and (culturally) preferred forms of accomplishing important social functions of mother-infant interactions such as attention initiation/maintenance, language acquisition support and affective communication. The first two functions have been shown to be accomplished by Deaf mothers most often using nonvocal modalities (Koester, 1992; Koester et al., 1998; Koester, Papoušek, & Brooks, 1995; Masataka, 1992; Reilly et al., 1990), while some limited aspects of affective communication possibly could be accomplished vocally by Deaf mothers interacting with deaf infants. When Deaf

mothers communicate their own level of affect through vocal modalities, they may receive proprioceptive feedback of the vocalization, and they then can attribute an appropriate emotion to that sensation (e.g. sensation caused by laughter could be associated with positive affect) . A detailed coding procedure would have to be employed to functionally label the maternal utterances from this study and to determine whether differential usage of modalities for basic social functions truly predicts the differences in ID speech characteristics observed in the current study.

Regardless of the specific reasons explaining the lower mean f_0 and lower measures of variability between and within utterances, it remains unclear whether this proves DAC to be an exception to the consistent findings of cross-cultural studies in this area that have posited the phenomena of increased pitch and variability in ID speech to be universal. Because vocal data of Deaf mothers interacting with adults (Deaf and/or hearing) were unavailable in the archival data set, comparisons of vocalizations from AD speech to those from ID speech were impossible, making any firm conclusions in this regard impossible as well.

Unexpected results concerning the Deaf mothers with hearing infants suggest that Deaf mothers with deaf infants are not using the prototypical feature of variability within utterances of ID speech to the extent that perhaps they are capable. Again, this is probably due to an alternative modality more appropriate to that interaction and culture for accomplishing functions which frequency variability might accomplish in most other types of mother-infant dyads and perhaps all other hearing cultures.

Unexpected Findings and Possible Explanations

Results from the current study indicate that Deaf mothers with deaf infants and Deaf mothers with hearing infants have similar mean fundamental frequencies and mean standard deviations while at the same time having disparate ranges. While the latter was an expected pattern in the results, the first pattern, especially when considered with the latter, was surprising. Perhaps physical and physiological constraints of vocal production result in Deaf mothers in the DIDP and HIDP groups having similar and possibly limited ranges of pitch, which then would be reflected in similar mean f_0 's and similar variability between utterances. However, Deaf mothers' variability within utterances reflected by the two types of ranges differs depending on the hearing status of the infant (hi-lo range expressed in semitones). Deaf mothers with hearing infants may be influenced to vocalize differently given the four factors described below.

First, infants prefer the variability characteristic of ID speech over that of AD speech (Cooper et al., 1990; Fernald, 1984, 1985; Fernald et al., 1987). Therefore, Deaf mothers may have increased their effectiveness in achieving and maintaining infant attention by using prototypical ID frequency modulation.

Second, Kato et al. (1983) demonstrated that full-term healthy newborns moved their bodies synchronously with their mothers' speech, though not with artificial sounds such as white noise or tapping sounds. If this type of infant-contingent responding continues through nine months of age, then perhaps Deaf mothers of hearing infants in this sample were receiving visual feedback in response to their vocalizations through contingent infant body movements.

Third, Fernald (1984) discussed affective communication in terms of regulating the infants' emotional state with contours characteristic of motherese and in terms of mothers communicating their own emotional state to the infant and to themselves. Deaf mothers with deaf infants may use vocalization to accomplish the latter of the two in ways that would benefit only their personal emotional regulation (through a proprioceptive feedback loop) not the infants' emotional state. Vocalization would not effectively accomplish the first type of affective communication in DIDP dyads since this modality is unavailable to the deaf infant. The Deaf mother with a hearing infant, on the other hand, may use vocalization to affectively self-regulate, to communicate her emotional state and to support the infant's emotional regulation. Deaf mothers with a hearing infants can effectively accomplish more functions using a vocal modality than can a Deaf mother with a deaf infant; this may account for the greater variability in the frequency within the vocalizations observed in the HIDP group compared to the DIDP group.

Fourth, Deaf mothers have similar registers available to them, but Deaf mothers of hearing infants maximize the variability available within the register to accomplish social functions with the whole range of modalities accessible to their infants. Deaf mothers intuitively may be providing a social context which supports their infants in the development of cross-modal perceptions. This is something that a Deaf mother with a deaf infant would do as well; however, in her supporting context, the mother would intuitively provide features such as kinesthetic, visual, tactile, gustatory, and vibratory stimuli, but not necessarily auditory stimuli. Any of

these factors may account for the differences in variability of frequency in vocalizations used by Deaf mothers of deaf infants and Deaf mothers of hearing infants, but, most likely, unique combinations of all four factors would differentially affect the vocal behavior of mothers in the HIDP group.

Another pattern of unexpected results indicated that hearing mothers of deaf infants had the highest mean f_0 of any group and also showed larger standard deviations and ranges (as measured in hertz). It was predicted that hearing mothers of hearing infants would be highest in these regards. Possible explanations of these unexpected results follow below.

Fernald et al. (1984) investigated the effects of infant state on mean f_0 and excursions (equivalent to highest-lowest frequency range of current study). Their data suggested (not significantly) that ID speech had a higher mean f_0 when directed at sleeping or drowsy infants than when directed at awake and quiet infants or awake and restless infants. Similar excursions were used to interact with sleeping or drowsy infants, awake and quiet infants, and awake and restless infants. This suggests that the trend seen in the mean f_0 across groups from the current study parallels the trend seen in the mean f_0 across infant states in Fernald et al.'s study. Both hearing mothers with a deaf infant and hearing mothers with a sleeping or drowsy hearing infant may perceive the infant as not interacting and so either consciously or less so begin to carry on a "monologue" instead of a "dialogue" (as Koester has described for hearing mothers with deaf infants, 1992, p. 366). Possibly the effect of carrying on a monologue elevates the mean f_0 . During such a monologue, the mother might affectively communicate to

herself positive emotions that maintain her sense of competence in the interaction.

Another more parsimonious explanation is that in both conditions there may be increased numbers of initiation or attention-getting bids due to mothers' perceptions that infants are not interacting. These types of bids have been associated with quickly rising contours (see Figure 1, p.15) in the motherese literature, and would account for higher mean f_0 in contexts where they are produced.

Fernald et al. (1991) described how target words that were stressed fell on exaggerated "pitch peaks" within an utterance. Such pitch peaks elevated the overall mean f_0 and increased the highest to lowest range (i.e. variability within utterance). Hearing mothers may be stressing, even overemphasizing, their words in attempts to achieve the language acquisition function with a vocal modality because they estimate a substantial potential for oral language acquisition in their infants. The hearing mothers' estimation or perception of their infants' abilities to acquire spoken English is probably based on experiences with the infants, but it is also based on the cultural beliefs of Mainstream American Culture (Stokoe, 1989).

Shute (1987) cites several instances where cultural beliefs affect ID speech, but one of the most vivid is her recount of Pye's (see Ratner & Pye, 1984) description of how Quiche Malayan adults wait for a child's first words before they speak to the child. In the current study, the mothers' *perceptions* of the child's hearing status may account for more of the fundamental frequency

variability than does the actual hearing status of the infant or mother. Also, a mother's attitudes towards verbal and signed languages could very well have an impact on the mother's use of language (in either modality). A mother who believes her deaf infant can acquire spoken language would then use an extreme form of ID speech, while a mother who believes that her deaf infant's best chance for language acquisition is ASL, might restrain herself from natural vocalizations. The current sample of mothers in the DIHP group certainly seems to back up the first of those alternatives.

Another explanation for the unexpected results concerning the DIHP group is that facial and body movements often occur concomitant to ID speech. This may be visually salient to the deaf infant whose increased attention and positive affect then reinforce these patterns in the mother (Koester et al., 1998) by the infants' increased attention and improved affect. The videotaped observations would have to be further analyzed to understand just how often the body movements and vocalizations co-occur. If such results confirmed that, indeed, such behaviors frequently occurred together, hearing mothers with deaf infants trying to incorporate more visual-gestural modalities or possibly ASL into their interactions would want to maintain their ID speech behavior in the interactional repertoire.

A final explanation for mothers in the DIHP group having higher mean f_0 and more variability than the other groups considers the impact of hearing aids and residual hearing on the deaf infants' responsiveness to their hearing mothers. Hearing mothers may actually be providing salient auditory stimuli to deaf infants

more frequently if vocalization is maintained in a higher register and wider excursions are used. The transformation to semitones reveals that the ranges that are so great in hertz would not be perceived as being any more variable to a hearing infant than would the narrower ranges produced in lower registers (HIDP and HIHP). The increased ranges may reflect hearing mothers' extreme excursions, which would include frequency segments within an utterance that may be perceived by a deaf infant with hearing aids and/or residual hearing.

Conclusions

One final cautionary note in considering the results of the current study. Since the results of studies describing ID speech in depressed (Bettes, 1988) and teenage mothers (Parker-Price et al., 1992) (e.g. mean f_0 's and variability that were lower and less exaggerated than nondepressed mothers or adult mothers) parallel some of the patterns of results from the current study, one might infer incorrectly that Deaf mothers with deaf infants are deficient in their parenting skills relative to mothers in the other three dyads. Instead, results should be seen as a further description of the different forms, perhaps reflecting cultural variations (Stokoe, 1989) which Deaf mothers and hearing mothers use to fulfill the same social functions critical to the mother-infant relationship. Essentially, Deaf mothers with hearing infants have much to learn from the interactions of hearing mothers with hearing infants, and hearing mothers with deaf infants have much to learn from the interactions of Deaf mothers with deaf infants. Early interventionists, behavioral scientists and linguists have a great deal to learn from the interactions of all four dyads.

Bettes' findings concerning depressed mothers do not seem to explain any of the patterns of results from the current study. Although the diagnosis of deafness in a child is very traumatic for most hearing parents and, indeed, the diagnosis of a child as hearing can be a disappointment to Deaf parents, the frequency measurements of the DIHP and HIDP do not represent a depressed state of ID speech. Since the time of the diagnosis or recognition of the infants' hearing status, support from friends, family and early intervention services may have ameliorated any effects that could have caused these mothers to be depressed. If any of the dyads had lowered pitch and decreased pitch variability, it was the Deaf mothers with deaf infants, and this pattern is better explained with the functional analysis presented above. Again, it is important to remember that non-vocal forms of motherese also occur in signed communication.

Some preliminary efforts have been made to analyze ID ASL derived from the archival data set used in the current study. Deaf mothers seemed to use bigger, slower, and more exaggerated signs with their infants than one might see in A-A signed conversation. Also, one handed signs were signed with two hands; specific palm orientations of signs were varied; and maternal facial expressions primarily conveyed positive affect. These mothers have even been observed molding their infants' hands and arms into approximations of signs. Furthermore, preliminary findings suggest that signed motherese effectively scaffolds language acquisition in these infants. For example, babies at nine months of age have been observed on these tapes manually babbling and even signing their own names. Because the archival data set contains video-tapes of these same infants up to

the age of eighteen months, it would be possible to assess how varying forms of ID Sign and ID speech affect infants' language, emotional regulatory behavior, attachment, and cognitive development. Following this line of investigation will be important to understanding how to functionally analyze the communicative efforts of Deaf mothers with deaf or hearing infants and hearing mothers with deaf infants.

It is imperative that research in this area will continue to map out the different roads which can be taken to reach effective communication, secure relationships and healthy, affective engagement between parents and infants. To meet the diverse needs of children, a diverse repertoire of skills and behavior must be identified and applied during the earliest parent-child interactions. In their efforts to identify the optimal intervention strategies for supporting deaf children and their families, it is tragic that the health and education communities have taken so long to turn to the true experts of deafness, the Deaf themselves,. And truly it has been the self-empowerment of the Deaf as a community that has led to this critical awakening in the health and education communities.

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