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Pitch characteristics of infant-directed speech affect infants' ability to discriminate vowels

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"Baby talk" or speech directed to prelinguistic infants is high in pitch and has exaggerated pitch contours (up/down patterns of pitch change) across languages and cultures. Using an acoustic model, we predicted that the large pitch contours of infant-directed speech should improve infants' ability to discriminate vowels. On the other hand, the same model predicted that high pitch would not benefit, and might actually impair, infants' ability to discriminate vowels. We then confirmed these predictions experimentally. We conclude that the exaggerated pitch contours of infant-directed speech aid infants' acquisition of vowel categories but that the high pitch of infant-directed speech must serve another function, such as attracting infants' attention or aiding emotional communication.

People tend to talk differently to infants than they do to other adults (Ferguson, 1964; Fernald, 1991; Papousek, 1992; Werker, Pegg, & McLeod, 1994), and the acoustic features of such infant-directed (ID) speech have been well documented. As compared with adult-directed (AD) speech, ID speech is high in pitch and has exaggerated pitch contours (e.g., Andruski & Kuhl, 1997; Fernald & Simon, 1984; Papousek, Papousek, & Haekel, 1987). ID speech has intrigued researchers for several reasons: (1) It is produced not only by mothers, but also by children, fathers, and other adults who have had little experience with infants (J. Dunn & Kendrick, 1982; Fernald et al., 1989; Trehub, Trainor, & Unyk, 1993), (2) The acoustic modifications of ID speech are similar across languages and cultures (Ferguson, 1964; Fernald, 1991; Fernald et al., 1989; Papousek, 1992; Werker et al., 1994), and (3) infants prefer to listen to ID over AD speech (e.g., Cooper & Aslin, 1990; Fernald, 1985; Werker & McLeod, 1989). In this paper, we examine the effects of the high pitch and exaggerated pitch contours of ID speech on vowel discrimination in 6-month-old infants.

It is likely that ID speech serves at least two different functions in development. Much evidence suggests that ID speech has the potential to benefit language learning (e.g., Bernstein Ratner, 1986; Fisher & Tokura, 1996; Kemler Nelson, Hirsh-Pasek, Jusczyk, & Cassidy, 1989; Kuhl et al., 1997), although some argue that ID speech does not aid language learning, because exposure to ID speech is not necessary for language learning (Pinker, 1994). Most of the positive evidence comes from analyses of ID speech, which show exaggerated linguistic cues at a number of levels. First, ID speech appears to exaggerate lexical and grammatical structure (Fernald & Mazzie, 1991; Kemler Nelson et al., 1989). Second, Kuhl et al. (1997) showed that mothers exaggerate the formant frequencies (vocal tract resonances) of ID, as compared with AD, point vowels (/i/, /a/, and /u/), which has the effect of maximally differentiating these vowel categories. Interestingly, Burnham, Vollmer-Conna, and Kitamura (2000) showed that vowel category exaggeration is specific to ID speech: "Pet-directed" speech is high in pitch but does not contain the exaggerated vowel categories of ID speech. There are fewer studies showing a direct benefit of ID speech on infants' vowel learning. However, one study showed that 1- to 4-month-old infants could discriminate a change in the second syllable of three-syllable utterances only when the second syllable had ID pitch contour, duration, and intensity (Karzon, 1985).

There is also evidence that caregivers use specific ID prosodic features to help modify their infants' state and to communicate emotional information (e.g., Fernald, 1993; Trainor, Austin, & Desjardins, 2000). The pitch and durational modifications of ID speech appear to reflect the vocal expression of emotion (Fernald, 1993; Trainor et al., 2000). According to this view, ID speech appears to differ from AD speech because AD is typically less emotional than ID speech. Evidence for this comes from acoustic analyses, which show that *emotional* AD speech does not differ prosodically in either pitch contour or temporal pattern from emotional ID speech, although these acoustic features do clearly differentiate different emotions (Trainor et al., 2000). Furthermore, Singh, Morgan, and Best (2002) have shown that infants' preference for ID over AD speech is based on the more positive affect of ID speech, as compared with AD speech. When affect is equated, infants' preference for ID speech disappears. That vocal expression of emotion might be primary is also supported by studies of a tonal language, Mandarin Chinese: When in

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conflict, mothers will sacrifice the phonemic use of pitch in order to maintain the high pitch and exaggerated pitch contours of typical ID speech (Grieser & Kuhl, 1988). An emotion hypothesis may also explain why ID speech is universally higher in pitch than is AD. There appears to be an intrinsic mapping between pitch and emotion (Scherer, 1986; Trainor et al., 2000; Trainor, Clark, Huntley, & Adams, 1997). Although the expression of fear can also be associated with high pitch in conjunction with a tense timbre (Scherer, 1986), across human cultures as well as across many animal species, low pitch tends to signal aggression, and high pitch tends to signal friendliness and nonaggression (Morton, 1977). Infants may well understand certain universal features of the vocal expression of emotion, just as they are able to process facial expressions of emotion at young ages (Barrera & Maurer, 1981). Infants prefer to listen to the high pitch and exaggerated pitch contours of ID speech over listening to the lower pitch of typical AD speech (Fernald, 1993; Fernald & Kuhl, 1987; Fernald & Simon, 1984; Papousek et al., 1987; Trainor & Zacharias, 1998), and they react differently to ID expressions of approval versus disapproval (Fernald, 1993).

In summary, ID speech appears to contain features that promote speech sound discrimination and features that reflect the vocal expression of emotion. It is possible that different ID features are involved in each of these functions, but it is also possible that some features may be involved in both functions. Pitch height and exaggerated pitch contours are clearly involved in the vocal expression of emotion (Trainor et al., 2000). In this paper, we consider the effects of these ID features on infants' discrimination of vowels. We first predict from acoustic theory that exaggerated pitch contours should enhance vowel discrimination. On the other hand, the same theory predicts that high pitch could actually impede vowel discrimination. The theory suggests, then, that the exaggerated pitch contours of ID speech promote language learning as well as emotional communication, whereas the high pitch of ID speech may serve only the emotional expression function. We then test our predictions of vowel discrimination with 6-month-old infants.

Vowels are differentiated according to the frequencies of their formants, which are resonances of the vocal tract that change frequency from vowel to vowel as vocal tract shape changes with articulation. But resonances can be detected only if there is energy in the signal close to the frequency of the resonance. The sound source for speech, the larynx, produces energy only at the frequencies of the fundamental and its harmonics, which are integer multiples of the fundamental. When there is a pitch contour present, the fundamental frequency changes, and the frequencies of the harmonics follow, whereas the frequencies of formant resonances remain relatively constant (Hillenbrand & Gayvert, 1993). Thus, when there is a large pitch change, it is likely that, at some point, the harmonics will sweep through the frequencies of the formants, thereby disclosing their locations (see Figure 1). On the basis of this analysis, we predicted better discrimination for vowels with large pitch contours than for steady-state vowels.

What about pitch height? The average fundamental frequency of a woman's normal speaking voice is around 220 Hz, and that of a man's is around 130 Hz (Peterson & Barney, 1952). However, a woman's ID speech is much higher–often over 300 Hz and ranging up to 600 Hz (Andruski & Kuhl, 1997; Fernald & Simon, 1984; Papousek et al., 1987). Thus, infants are typically hearing speech that is very high in pitch during the time when they must learn the vowel categories of their native language (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Polka & Werker, 1994). In higher pitched sounds, the bands of energy (harmonics) are more widely spaced than in lower pitched sounds (see Figure 1). The frequencies of the formant resonances can be accurately detected only if there is energy in the signal close to the frequencies of the resonances. Thus, the location of the formants can be difficult to determine with high-pitched voices (Lieberman & Blumstein, 1988), leading to the prediction that high-pitched vowels should be more difficult to discriminate than low-pitched vowels (Lehiste & Meltzer, 1973; Ryalls & Lieberman, 1982). Earlier work has shown that infants as young as 8 weeks of age can discriminate between vowel categories when typical male voices are used (Kuhl & Miller, 1982; Swoboda, Kass, Morse, & Leavitt, 1978; Swoboda, Morse, & Leavitt, 1976; Trehub, 1976). Although one study used highly distinct vowels in the female range (Kuhl, 1979), infants' discrimination of vowels in the range of the ID speech that infants typically hear has not been tested previously.

In sum, we predicted that ID pitch contours would enhance vowel discrimination but that high pitch would not, and might even hurt discrimination.

METHOD

Participants

Ninety-six infants between 6 and 7 months of age were tested (half male, half female). All the infants were healthy, had been born at term (38–42 weeks gestation), and had no family history of hearing impairment. An additional 48 infants were excluded for failing to pass training.

Stimuli

Using SenSyn (Sensimetrics Corporation) software, we synthesized 500-msec tokens of two English vowels, /i/ as in *heed* and /ɪ/ as in *hid* (Table 1), that are known to be discriminable to very young infants (Swoboda et al., 1978; Swoboda et al., 1976) when presented in the male pitch range (80–125 Hz). For each vowel, we created a low- and a high-pitched steady-state version, as well as a low- and a high-pitched falling contour version reminiscent of the comfort contour in the ID speech style (Fernald & Simon, 1984; Papousek et al., 1987). The low–steady version was in the range of a typical female voice (240 Hz), and the high–steady version was more typical of ID speech (340 Hz). The low–contour version fell from 240 to 140 Hz, and the high–contour version fell from 440 to 340 Hz. We used synthesized vowels because this is the most effective way to manipulate these features while controlling for all other potential differences. Although some conjunctions of these features may be uncommon in

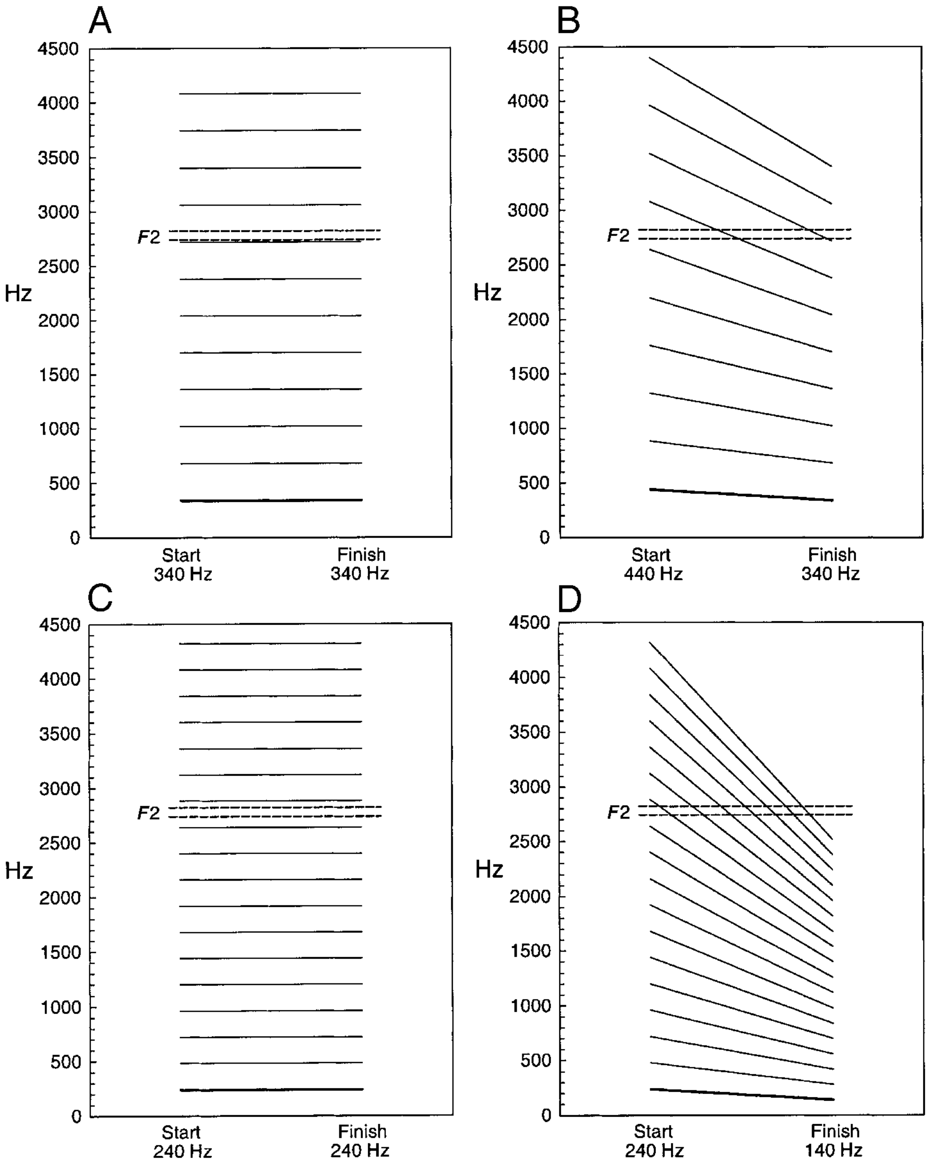

Figure 1. The harmonic structures for steady-state tokens are shown in panels A and C, and those for contour tokens are shown in panels B and D. Note that for the higher pitched tokens, shown in panels A and B, the harmonics are more widely spaced than those for the lower pitched tokens, shown in panels C and D. In the steady-state tokens (panels A and C), the harmonics fall outside the second formant (*F*2), whereas when pitch contour is added (panels B and D), the harmonics pass through the *F*2 band.

the real world (e.g., high–steady vowel sounds may be found primarily in singing), it is necessary to use such stimuli in order to test the independent effects of pitch height and pitch contour. In fact, testing discrimination with such stimuli may inform us as to why some conjunctions of features are uncommon.

During testing, sounds were generated with an Audiomedia card in a Macintosh IIci computer connected to a Denon amplifier (PMA 480) and a single GSI loudspeaker, the latter located in a sound-attenuating chamber (Industrial Acoustics Co.). Under the loudspeaker was a box with a smoked Plexiglas front that contained an animated toy; only during reinforcement for correct head turns (see the Procedure section) were the lights inside the box illuminated, making the animated toy visible.

Procedure

Twenty-four infants were tested on their discrimination of /i/ and /ɪ/ in each of the four pitch conditions, low–steady, high–steady, low–contour, and high–contour. After obtaining informed consent from the parent, a conditioned head-turn procedure was run. The standard vowel (for half the infants, it was /i/; for the other half, it was /ɪ/) was repeated every 2 sec throughout the test from a loudspeaker located on the infant's left. The infant sat on his or her par-

Table 1
Formant Frequencies in Herz for /i/ and /ɪ/

Format	/i/	/ɪ/
*F*1	310	430
*F*2	2790	2480
*F*3	3310	3070
*F*4	4031	4188

Note—Frequencies for formants *F*1, *F*2, and *F*3 were from Peterson and Barney (1952); frequencies for *F*4 were calculated according to Syrdal (1985). Bandwidths were from H. K. Dunn (1961).

ent's lap across from the experimenter, with the speaker and toy box on the infant's left. Both the parent and the experimenter listened to masking music over headphones. When the infant was attentive and facing forward (toward the experimenter), the experimenter indicated to the computer via a button box that the infant was ready for a trial. Half of the trials were change trials, on which one repetition of the standard vowel was changed (i.e., either from /ɪ/ to /i/ or from /i/ to /ɪ/); half of the trials were control trials, on which the standard vowel simply continued. The experimenter pressed a second button connected to the computer whenever the infant turned his or her head at least 450 to the left. Head turns on change trials, *hits*, were rewarded with 3 sec of lights and toys; head turns on control trials, *false alarms*, were not. The 24 trials of the test (12 change and 12 control) were preceded by a training phase designed to familiarize the infants with the contingency between a head turn in response to a change in the vowel and the animated toy reinforcer. During training, the vowel on change trials was 5 dB louder than the repeating standard vowel. The infants were required to make four consecutive correct head-turn responses within 20 trials in order to proceed to the test phase.

RESULTS

A d' score was computed for each infant, and the scores were submitted to an analysis of variance with four between-subjects factors: condition (contour, steady), pitch (high, low), standard vowel (/i/, /ɪ/), and sex (male, female).[1] As can be seen in Figure 2, the infants' discrimination was superior for low-pitched over high-pitched vowels [significant main effect for pitch; $F(1,80) = 8.55, p < .005$]. In addition, the infants discriminated the vowels in the downward contour condition more easily than the same vowels in the steady-state condition [significant main effect for condition; $F(1,80) = 25.21, p < .0001$]. No other main effects or interactions were significant. One-sample *t* tests indicated that discrimination, as indexed by d', exceeded chance (0) in both contour conditions (high–contour and low–contour) and in the low–steady condition (all *p*s < .0004). Only in the high–steady condition was performance at chance levels ($p > .4$).

In the real world, ID speech is rarely steady in pitch. Before concluding that high pitch may actually impede vowel discrimination, we compared performance between the high–contour and the low–contour conditions only. Performance was still superior for low-pitched over high-pitched vowels [$F(1,40) = 7.42, p < .01$].

DISCUSSION

The main conclusion is that ID speech contains features that help infants learn the vowel categories of their language. In the present study, we showed that the exaggerated pitch contours of ID speech facilitate vowel discrimination in infants at the time when they are learning their native language vowel categories (Kuhl et al., 1992; Polka & Werker, 1994). The pitch contours of ID speech are particularly interesting because they appear to serve more than one function. The present work demonstrates their importance in vowel learning. However, previous work has shown that ID pitch contours are also important in the vocal expression of emotion to prelinguistic infants (Fernald, 1993; Trainor et al., 2000).

The present study demonstrated that another feature of ID speech, high pitch, does not facilitate vowel discrimination but actually impedes it. There are several possible reasons for why it is universal to address infants by using high pitch, despite the potential hazards for vowel learning. Because the auditory system matures first for high frequencies (Schneider & Trehub, 1992), it is possible that infants simply can hear higher pitched voices better than lower pitched voices and will therefore show increased attention to the former. This, in turn, would prompt adults to use high pitch with infants. Another possibility concerns the vocal expression of emotion. There is substantial evidence that the prosody of ID speech communicates emotional information to infants who cannot yet understand the words (Fernald, 1991, 1993; Papousek et al., 1987; Trainor et al., 2000). Thus, caregivers may use high pitch in order to communicate their benevolent intentions to the infant.

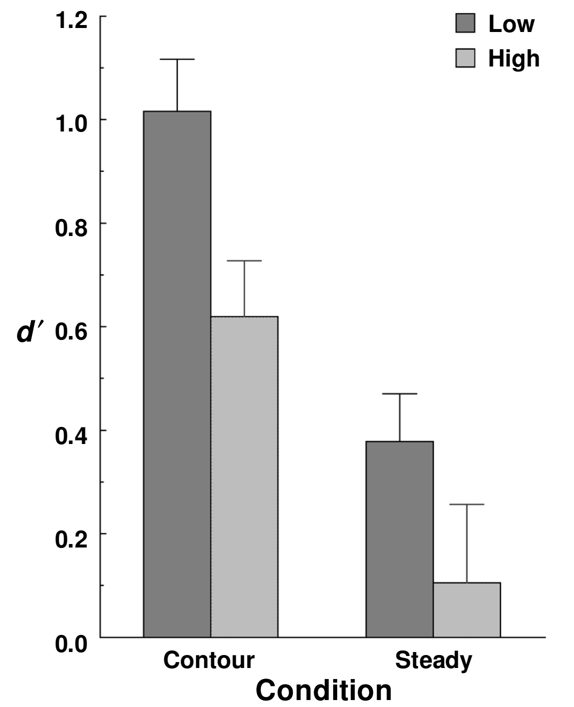

Figure 2. The d' scores are plotted as a function of pitch and of contour versus steady state. Performance is significantly above chance levels (0) for all the conditions except high–steady. Performance is significantly better for low- than for high-pitched vowels and for contour than for steady-state vowels.

An interesting question remains concerning the evolutionary origins of ID speech. Perhaps it initially evolved to serve one function (vocal expression of emotion) but was conveniently recruited to fulfill another (vowel discrimination) as that evolutionary pressure arose. In this context, it is interesting to consider what happens when there is a conflict and a particular feature aids one function but impedes another. Interestingly, in the case of pitch height, emotional communication or attentional functions appear to win out. High pitch is universally used in ID speech even though, as we have shown, it impairs vowel discrimination. Previous work has shown that, in tonal languages, the high pitch and exaggerated pitch contours of ID speech are maintained even though this obscures the phonemic use of pitch and pitch contour (Grieser & Kuhl, 1988). Such evidence is consistent with the idea that the vocal expression of emotion is phylogenetically older than the use of language. Such a conclusion, of course, in no way diminishes the importance of ID features that promote vowel leaning but, rather, highlights the complex interplay of features and functions involved in ID speech. Of primary significance is the conclusion that ID pitch contours promote vowel discrimination, as well as serve an emotional communication function.

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NOTE

1. It is assumed that the occasional hit or false alarm scores of 0 that we obtained arose from sampling error owing to the small numbers of trials that can be obtained from infants. In order to calculate d' values, we added ½ to the number of head turns on change and on control trials and divided these by the number of trials plus one (i.e., 13) in order to obtain hit and false alarm rates. This transformation has little effect on the proportions and maintains the relative ranking of scores (see Thorpe, Trehub, Morrongiello, & Bull, 1988). It should also be noted that the results remain the same whether d', A', or proportion correct is used as the dependent measure in the analysis. Average proportions for hits and false alarms were .42 and .10 for low–contour, .37 and .18 for high–contour, .48 and .33 for low–steady, and .38 and .34 for high–steady.

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