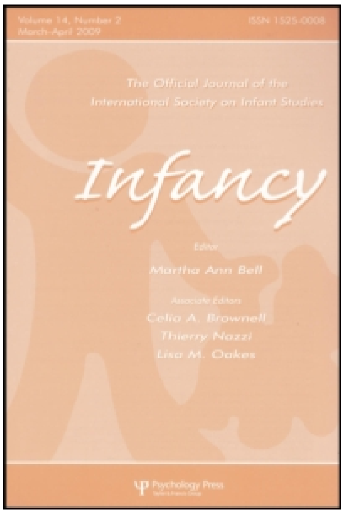

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Infant-Directed Speech Is Modulated by Infant Feedback

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When mothers engage in infant-directed (ID) speech, their voices change in a number of characteristic ways, including adopting a higher overall pitch. Studies have examined these acoustical cues and have tested infants' preferences for ID speech. However, little is known about how these cues change with maternal sensitivity to infant feedback in the context of interaction. In this study, each mother watched her infant (located in an adjacent sound booth) on a video screen and talked to him or her through a microphone. The mother believed that her infant could hear her voice and she attempted to make her infant happy through her vocalizations. In reality, the infant could not hear her voice. The mother's ID speech was analyzed in real time for changes in mean pitch. For half of the infant–mother dyads an experimenter surreptitiously positively engaged the infant when the voice analysis revealed a rise in pitch, thereby producing positive reinforcement to the mother for natural higher pitched ID speech. The other half were reinforced for lower pitched ID speech. Mothers raised their pitch significantly more in the former than the latter condition, illustrating that the pitch of ID speech is dynamically affected by feedback from the infant.

When adults communicate with infants in speech or song, their voice quality assumes a distinctive infant-directed (ID) quality. Acoustical analyses of ID speech have identified a number of characteristic properties relative to adult-directed (AD) speech: higher overall pitch, expanded pitch range, characteristic intonational contours, longer pauses, shorter utterances, and increased repetition (Fernald & Simon, 1984; Katz, Cohn, & Moore, 1996; Stern, Spieker, Barnett, &

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MacKain, 1983; Stern, Spieker, & MacKain, 1982). Similar acoustical properties have been shown in ID singing (Trainor, Clark, Huntley, & Adams, 1997). Although linguistic and cultural groups differ in the degree of these prosodic modifications, their cross-cultural presence suggests that ID communication reflects a universal parental behavior (Fernald et al., 1989; Grieser & Kuhl, 1988; Kitamura, Thanavishuth, Burnham, & Luksaneeyanawin, 2002; although see Ratner & Pye, 1984).

This vocal behavior may be important for a number of reasons. In the context of parent–child interaction, ID speech may aid in regulation of emotion in the infant (Trainor, Austin, & Desjardins, 2000), the formation of attachment relationships (e.g., Singh, Morgan, & Best, 2002; Trainor et al., 2000), the guiding of infants' attention (e.g., Kaplan, Goldstein, Huckeby, Owren, & Cooper, 1995), and the acquisition of language (e.g., Fernald & Mazzie, 1991; Thiessen, Hill, & Saffran, 2005; Werker et al., 2007).

Most research in this area has examined either infant perception and preference, or characteristics of maternal production of ID speech. Perceptual studies have shown that infants are sensitive to the prosodic modifications of ID speech and prefer to listen to ID over AD speech and song (e.g., Cooper & Aslin, 1990; Fernald, 1985; Nakata & Trehub, 2004; Pegg, Werker, & McLeod, 1992; Trainor, 1996). Even hearing newborns of deaf mothers show preferences for ID over AD song in both Japanese and English, suggesting that infant responses may not depend on prenatal experience with the mother's voice (Masataka, 1999). The ID quality involves a combination of spectral and temporal modifications, but it appears that infants' preferences are predominantly determined by the pitch information of ID speech, rather than the temporal or intensity modifications, at least at 4 months of age (Cooper & Aslin, 1994; Fernald & Kuhl, 1987).

Adults communicate with infants for a variety of reasons, and it is therefore not surprising that ID speech can take a variety of forms. For example, particular intonational contours may distinguish between ID utterances intended for different purposes, such as attracting the infant's attention, showing approval, or providing comfort (Fernald, 1989, 1992; Katz et al., 1996). Furthermore, the vocal expression of different emotions (i.e., love and comfort, fear, and surprise) are associated with distinct pitch and temporal contours (Trainor et al., 2000).

The interaction between mothers and their infants appears to be a bidirectional process of mutual and reciprocal influence (Murray & Trevarthen, 1985). In terms of the content of speech to infants, Murray and Trevarthen (1986) found increased use of interrogatives when mothers spoke to their 2-month-olds via live video, than when they spoke to delayed replays (believing the video was live), suggesting that contingent behavioral cues from their infants are important. In terms of speech prosody, there are clear and readily distinguishable acoustical differences between ID and simulated ID speech and song (Fernald & Simon, 1984; Jacobson, Boersma, Fields, & Olson, 1983; Trehub, Unyk, & Trainor, 1993), suggesting that mothers are particularly sensitive to the physical presence of their infants.

Despite this evidence suggesting the bidirectional nature of mother–infant interaction, little is known about the particular processes involved. For example, infants' positive behavioral responses to ID speech have been documented in numerous preference studies, but we know little about how the pitch of mothers' ID speech is influenced by the behavioral manifestations of infants' preferences. If the particular form of ID speech is indeed dependent on the mothers' communicative intent, then mothers should be sensitive to positive and negative responses from their infants, and should adjust their vocalizations accordingly.

A controlled examination of the dynamics of maternal speech and infant responses is difficult in naturalistic contexts. As schematized in Figure 1a, the mother's ID speech both influences and is influenced by the infant's behavioral responses, which reinforce the mother for her ID speech. In this study, we examined mothers' sensitivity to feedback from their infants by experimentally manipulating the contingencies of reinforcement mothers received from their infants. This was done by physically separating the mother and infant in different rooms, and controlling their experiences independently to either preserve or reverse the natural pattern of reinforcement. As illustrated in Figure 1b, mothers spoke to their infants

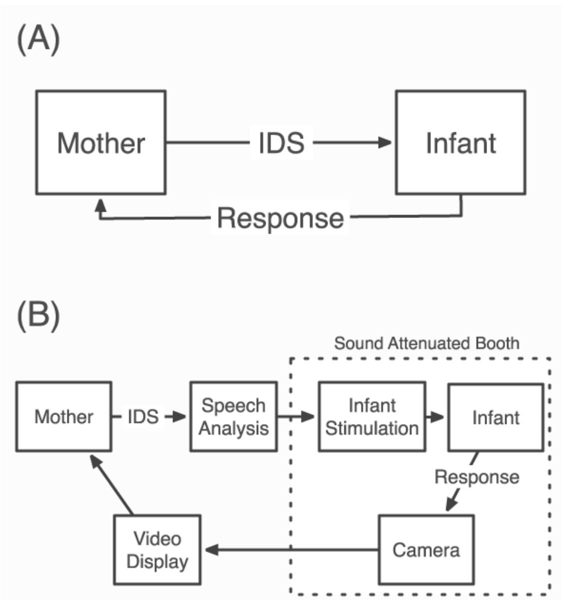

FIGURE 1 A schematic illustration of (a) the natural means of interaction in infant-directed speech, and (b) the experimental setup used to manipulate the contingencies of reinforcement in infant-directed speech.

as they watched them in real time on a video display and were instructed to try to make their infants happy. However, unbeknownst to the mothers, infants did not hear their mother's voice, but rather responded to an experimenter present with the infant in the sound-attenuated booth. The experimenter (out of view of the camera) alternately stimulated or ignored the infant, depending on the output of the real-time acoustical analysis of the mothers' speech to the infant.

In one condition, the natural contingency of reinforcement was replicated by cuing the experimenter to positively stimulate the infant whenever the mother's speech adopted characteristic ID properties (i.e., higher pitch). The mother was thus reinforced, or experienced a greater potential for reinforcement,[1] for producing high-pitched ID speech. In contrast, in another condition the experimenter was cued to stimulate the infant when the mother spoke at a lower pitch to her infant, which is not characteristic of ID speech.

By experimentally manipulating the infant's responses to the mother, it is therefore possible to examine the mother's sensitivity to infant feedback. This scenario, although artificial, permits an examination of the degree to which the production of ID speech is amenable to learning and experience. Can experience with different contingencies of reinforcement in the laboratory affect this long-standing form of maternal behavior?

METHOD

Participants

Eighteen mother–infant dyads participated. Infants were 4 months old. Mothers were recruited from maternity wards at several local hospitals. All infants were healthy, born full term, and had no family history of hearing impairment. Each dyad was assigned to one of two experimental reinforcement conditions (high-positive or low-positive), described later.

Apparatus

As illustrated in Figure 1b, in contrast to natural face-to-face interaction, mother–infant dyads were physically separated during testing. Infants were seated in a sound-attenuating booth [single walled, Industrial Accoustics Company (IAC)] and could neither see nor hear their mother, who was seated outside the booth. The mother watched her infant's face in real time on a silent video screen outside the

[1]Unlike simpler cases of operant conditioning, the potential for reinforcement is dependent and mediated by a number of factors: the infant's consistent positive reaction to the "hidden" experimenter and the mothers' detection and judgment of these infant feedback cues as positive.

booth. Mothers' speech was recorded using an AKG Dynamic Pressure Gradient microphone connected through a TASCAM US-122 interface connected to an Apple G5 computer running a custom program created using MAX/MSP.

Speech Analysis Procedure

The speech was recorded at a sampling frequency of 44.1 kHz and analyzed using a Fourier transformation. The continuous signal was segmented into a series of overlapping temporal windows 4,096 samples (or 93 msec) in length, with a hop size (temporal interval between the beginning of adjacent windows) of 512 samples (11 msec). A Blackman–Harris windowing procedure was used to avoid the effects of abrupt onsets and offsets. The fundamental frequency in a given window was estimated on the basis of peaks in the amplitude spectrum, using a maximum likelihood procedure. Overall, this analysis produced estimates of the fundamental frequency (in Hz), a measure of the overall amplitude of the speech sample and the amplitudes of individual frequency components (in dB with an arbitrary reference) that were identified as peaks in the spectrum for each window, at a rate of 86 windows per second.

To restrict this analysis to parts of the signal that carry valid pitch information, windows were excluded if they did not meet a number of criteria. First, the signal needed to exceed the background noise level in the room when the mother was not speaking by 15 dB. Second, the amplitude of the lowest frequency peak in the spectrum needed to make a significant contribution to the overall amplitude of the signal. In effect, this criterion selected for vowel sounds and excluded the more noise-like stop consonants and fricatives. Finally, windows were excluded in which the fundamental frequency was not within a plausible range of adult female ID speech (between 100 and 1,000 Hz).

Prior to testing, the baseline AD pitch of each mother's voice was calculated by recording her reading aloud from a magazine article. Each mother read until 200 valid windows (in terms of the three criteria just described) were obtained, and the average of these 200 samples was calculated.

Mother–Infant Interaction Procedure

Mothers were then asked to communicate (in words or song) through the microphone to their infants, who they watched in real time on a silent video display. Mothers were simply instructed to try to make their infants happy. They were unaware that their infants could not actually hear their voices in the sound booth. Mothers' speech was continuously recorded and analyzed. However, for the purposes of controlling the experiment and analysis of the data, the continuous recording was segmented into 5-sec-long trials, of which there were 105 (lasting 8 min, 45 sec)—the largest number of trials common to all dyads in both conditions. The mean fundamental frequency across all valid windows within each trial was calculated and this value determined the kind of stimulation the infant would receive (positive or neutral) depending on whether the mother–infant dyad was assigned to the high-positive or low-positive condition.

In the high-positive condition, when the mother's pitch rose above her baseline pitch by any amount (baseline initially set to the mean frequency of her AD reading), an experimenter in the booth facing the infant, but out of view of the camera, received a cue (on a video screen) to engage and arouse the infant in a variety of ways including calling out the infant's name, asking "rhetorical" questions, and making statements of fact or opinion (e.g., "Hey Benjamin! Whatcha doing, baby? Aren't you cute!"). When her pitch fell below the baseline by any amount, the experimenter received a cue to adopt a neutral expression. The experimenter attempted to follow the cues as closely as possible, without switching midphrase. The high-positive condition therefore preserves the natural contingency present in normal mother–infant interaction—higher pitched ID speech leads to positive reactions from the infant. In contrast, in the low-positive condition, when the mother's pitch rose above her baseline the experimenter was cued to adopt a neutral expression. Studies of still-face expression have shown that this has an observable stressful effect on infants (e.g., Toda & Fogel, 1993; Weinberg & Tronick, 1994). When her pitch fell below the baseline, the experimenter received a cue to engage the infant. Thus, in the low-positive condition the natural contingency was reversed with the mother receiving positive feedback from her infant when her speech was lower pitched and therefore less characteristic of ID speech.

Although the baseline was initially set to the mean frequency obtained while reading the magazine article, as the experiment progressed the baseline varied adaptively as a function of the pitch of mothers' ID speech to their infants within the experiment. Specifically, the baseline was set to the mean pitch of the previous five trials. Thus, as mothers increased or decreased their pitch to receive positive feedback from their infants, the criterion for continued reinforcement also increased or decreased. There are a number of reasons for choosing an adaptive baseline over a baseline with a fixed frequency. In pilot studies, the baseline was fixed at either the AD baseline, or two semitones above. In these studies, ID speech was consistently above this baseline in both the high-positive and low-positive conditions. As a result, mothers in the high-positive condition were almost always reinforced and mothers in the low-positive condition were almost never reinforced. Thus, the desired contingency between the pitch of the mother's voice and positive feedback from the infant rarely occurred. However, the adaptive baseline used here ensures equal exposure to both the presence and absence of positive feedback from the infant because the feedback is contingent on whether the pitch of current ID speech rises above or falls below the average pitch of recent trials. In the high-positive condition, as the mother increases her pitch she receives positive feedback, but must continue to raise her pitch to maintain the positive feedback. In the low-positive condition as the mother decreases her pitch, she must continue to further decrease her pitch to main positive feedback. Thus over time, one might expect that mothers in the high- and low-positive conditions would show increasingly divergent pitch responses.

RESULTS

For each mother, we obtained a baseline measure of the fundamental frequency of her AD speech, a trial-by-trial record of the fundamental frequency of her ID speech over the course of interaction with her infant, and a corresponding record of whether or not the mother received positive reinforcement from her infant on each trial. Mean AD baseline pitch for the high-positive and low-positive groups was 198 Hz (SD = 18 Hz) and 196 Hz (SD = 20 Hz), respectively, and did not differ significantly. Thus, the two experimental groups were comparable in that they did not exhibit pitch differences prior to their experience in the experimental task.

For each mother, the mean fundamental frequency was calculated during each of the 5-sec-long trials. This was done by averaging the fundamental frequencies of the variable number of valid windows (i.e., those not excluded according to the amplitude and spectral criteria described earlier), within the 5-sec interval. To track changes across the series of trials, this mean frequency value was normalized to the individual mother in terms of the proportion of an octave that it was above that mother's AD baseline frequency (i.e., $\log_2(f_{0\text{-IDS}}/f_{0\text{-Baseline}})$).

The mean pitch across trials for the high- and low-positive groups is shown in Figure 2. The initial equivalence of the two groups was confirmed by the lack of a significant difference in the average pitch for the first five trials: high positive (M = .57 octaves), low positive (M = .51 octaves), $F(1, 16) = 0.20$, $p = .66$, $\eta2 = 0.012$. The groups diverge in pitch over the following 100 trials, with the high-positive group significantly higher (M = .66 octaves or about nine semitones above baseline) than the low-positive group (M = .47 octaves, or six to seven semitones), $F(1, 16) = 2.20$, $p = .043$, $\eta^2 = 0.232$. This divergence is demonstrated by significant positive correlation (or slope) of pitch over trials in the high-positive group (r = .324, $p < .001$), but not the low-positive group (r = –.006, *ns*). Finally, the slope coefficients for the high-positive and low-positive groups were significantly different ($t = 2.31$, $p < .05$).

DISCUSSION

The main finding of this study was that mothers produced higher ID speech in the high-positive condition (i.e., reinforced for high-pitched ID speech) than in the low-positive condition. This demonstrates maternal sensitivity to feedback pro-

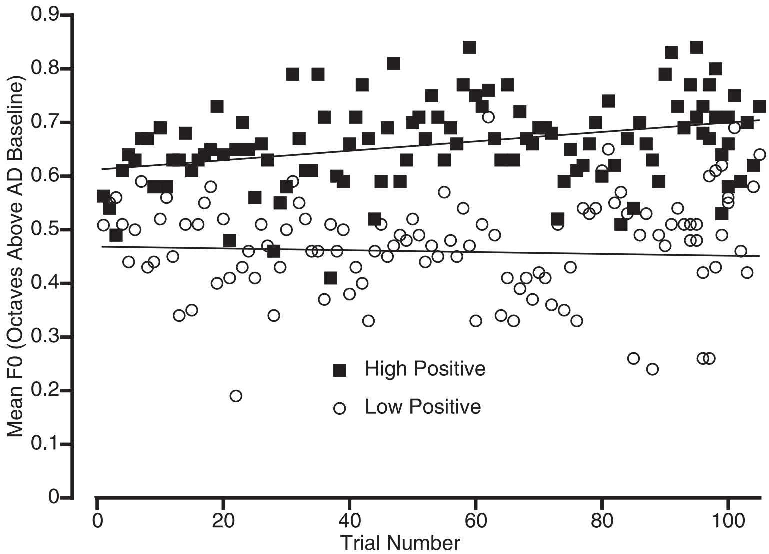

FIGURE 2 The mean pitch (F0) of infant-directed speech across 5-sec-long trials for mothers in the high-positive and low-positive conditions expressed in terms of octaves above their adult-directed baseline pitch.

duced by infants, and that this sensitivity affects the pitch of mothers' ID speech. The observed elevations in mean pitch ID speech above AD baselines are higher than those observed in previous studies (e.g., Fernald & Simon, 1984: +0.34 octaves; Cooper & Aslin, 1990: +0.39 octaves), although strict comparisons are difficult given the varying methods. Nevertheless, one possibility is that these larger pitch shifts may reflect the effect of physical separation, with mothers trying harder in their ID speech because it was their only means of communication. More likely, however, this difference reflects our use of a read speech for the AD baseline, which has been found to be lower in mean pitch than spontaneous speech (Daly & Zue, 1992; Hirschberg & Nakatani, 1996).

Feedback is important when one considers the various functions of ID speech. Whether the paralinguistic "message" conveyed is one of emotional expression and regulation (Singh et al., 2002; Trainor et al., 2000), attentional control (Kaplan et al., 1995), or language acquisition (e.g., Fernald & Mazzie, 1991; Thiessen et al., 2005; Werker et al., 2007), infant feedback may provide important signals to the adult as to how the "message" was received. In this vein, paralinguistic modifications of speech appear to be related to the receiver's capacity to understand the message. For example, in a comparison of ID and pet-directed (PD) speech, Burnham, Kitamura, and Vollmer-Conna (2002) found that adults hyperarticulated vowels in their speech to their infants, but not to their pets, despite similar elevations in pitch. In other words, PD speech may be used to regulate emotion and attention, but is likely not aimed at language acquisition. Similarly, interaction between mothers and their deaf infants differs in many ways from interactions with normal hearing infants (Koester, 1995; Koester, Brooks, & Karkowski, 1998). In tests of ID speech to hearing-impaired infants who use cochlear implants, Bergeson, Miller, and McCune (2006) found that ID speech more closely corresponded to ID speech to normal hearing infants matched in terms of auditory experience rather than chronological age.

One interesting aspect of mothers' sensitivity to feedback was the asymmetric effect of reinforcement in the high- and low-positive conditions. Reinforcement for higher pitched ID speech drove mothers' ID speech higher, but reinforcement for low ID speech did not drive the low-positive mothers' ID speech lower. This finding suggests that constraints exist in the degree to which ID speech is amenable to learning. The contingencies at play in the high-positive condition are consonant with the mothers' instincts and 4 months of previous interaction with their infants—factors that cannot easily be overridden (in the low-positive group) by less than 10 min of experience in the laboratory. Furthermore, the nature of the interaction may be different in the case of low-pitched ID speech, in which mothers may adopt a more soothing tone in response to infants' negative emotional displays. In terms of learning theory, the reduction in the infants' negative emotion would constitute a negative reinforcer for the mother.

Beyond the specific results demonstrated here, this study provides a methodological precedent for future studies of ID speech. Elevated pitch is only one aspect of ID speech, but by using real-time digital signal processing techniques the current work can be extended to examine the role of other aspects of ID speech in mother–infant interaction. For example, ID speech can be filtered in various ways to either preserve or remove phonetic or prosodic information. Sine-wave versions of ID speech could be extracted from the online recording, and the intonational contours could be artificially expanded, constricted, or inverted. This study provides a starting point and new methodology for studying questions in this domain. Research examining the functional operation of various acoustical cues in the context of real-time mother–infant interaction would be a logical extension. It would merge previous foundational work examining these cues using offline analysis of recordings (e.g., Fernald & Kuhl, 1987) and infant preference procedures (e.g., Cooper & Aslin, 1994).

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