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Accommodation in mean f_0 during mother–infant and father–infant vocal interactions: a longitudinal case study*

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ABSTRACT

Reports that infants imitate the vocal pitch characteristics of adult caregivers (e.g. Lewis, 1936/1951) include Lieberman's (1967; Lieberman, Ryalls & Rabson, 1982) claim that infants differentially adjust their vocal pitch or fundamental frequency (f_0) towards that of their caregivers, resulting in higher mean pitch when interacting with mothers than when interacting with fathers. However, a recent cross-sectional study of infants at ages 0;8 to 0;9 and 1;0 failed to find evidence of differential pitch adjustment toward male and female caregivers (Siegel, Cooper, Morgan & Brennesie-Sarshad, 1990). A more sensitive test of Lieberman's claims would be to use a longitudinal design, with spontaneous recording sessions repeated over many months. The current study presents data from a longitudinal case study of an infant recorded at ages 0;3, 0;7, 0;10, 1;3 and 1;5 interacting with each of her parents in spontaneous play sessions and in isolated play. The infant in our study did not demonstrate significant adjustment of her vocal pitch in the direction of either parent. However, we did find evidence for consistent adjustment by the parents, in accord with the literature on infant-directed speech and mother–infant dyadic interactions, which

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suggest that the parents adjusted their behaviour to suit the infant more than vice versa.

INTRODUCTION

During social exchanges adults often modify various aspects of their vocal and non-vocal behaviour in ways that increase the interactants' similarity on those dimensions. These mutual adjustments occur on non-content parameters of speech such as speech rate (Street, 1984), vocal intensity (Natale, 1975), pause duration (Welkowitz & Feldstein, 1976; Capella & Planalp, 1981) and vocalization duration (Matarazzo & Wiens, 1972). Speech accommodation theory holds that communicators are motivated to adjust these and other aspects of their speech styles as a means of expressing attitudes and intentions (Street & Giles, 1982). The mutual modification of vocal and non-vocal behaviours in mother-infant interactions (Beebe, Stern & Jaffe, 1975; Beebe, Jaffe, Feldstein, Mays & Alson, 1985; Cohen & Tronick, 1988) demonstrates that the tendency to adapt behaviours during communicative interactions begins very early in life, and suggests that some form of mutual entrainment might occur between mothers and infants during early social interactions. Often cited as evidence of the early tendency toward communicative accommodation are claims by Jakobson (1968), Crystal (1975), Helfrich (1979) and Lieberman, Ryalls & Rabson (1982) that infants converge their vocal pitch or mean fundamental frequency (f_0) toward that of adults during vocal interactions (e.g. Natale, 1975; Street & Giles, 1982; Street & Cappella, 1989). Unfortunately, these reports of mean f_0 convergence have been either anecdotal or based on small numbers of recordings of one or a few infants. The claim for infant f_0 convergence has not been supported in a recent controlled experiment with a larger sample of infants (Siegel, Cooper, Morgan & Brennesie-Sarshad, 1990). The present study provides an in-depth longitudinal case study of vocal interaction between an infant and both parents to evaluate more systematically the claim for pitch convergence in infancy.

It has been claimed for many years that infants are especially attentive to intonation and register properties of speech (e.g. Lewis, 1936/1951). Recent experimental studies have confirmed that some aspects of intonation, especially the wide pitch excursions common in infant-directed speech, are important in eliciting and maintaining infant attention (Fernald, 1984; Fernald & Kuhl, 1987). However, some reports in the literature go beyond suggesting that intonation has a heightened perceptual salience for infants. Claims have been made that infants spontaneously imitate, or at least accommodate their own voice pitch to the pitch or pitch contours of their adult caregivers (e.g. Lewis, 1936/1951; Lieberman, 1967, 1984; Trevarthen, 1974; Papousek & Papousek, 1981). These claims have been made largely on the basis of comparisons involving small numbers of infants and utterances. For example, Lewis (1936/1951) reported that infants imitate adult pitch patterns in the first months of life. Lieberman (1984) reported an infant age 0;1·14 matching absolute pitch and pitch contours produced by its mother in a single brief recording session. Lieberman (1967) and Trevarthen (1974) have also described individual parent–infant dyads in which vocal imitation occurred. More recently, Papousel & Papousek (1981) reported that an infant aged 0;2 'indistinctly matched a pitch or short intonation contours', and by age 0;10 the infant imitated speech-like intonation contours. At age 0;11·14, this infant was noted to correctly hum melodies and rhythms of songs. Crystal (1975) described an infant aged 1;0 who used different registers when speaking for different stuffed animals.

These studies, though suggestive, fail to take into account important conceptual and methodological concerns that must be addresed before claims of infant imitation can be considered valid. We note several concerns identified by Meltzoff & Moore (e.g. 1983) with regard to imitation in general, and later related specifically to vocal imitation by Kuhl & Meltzoff (1988), that are especially germain in the context of pitch imitation/accommodation. First, basic experimental design concerns must be addressed to ensure that it is the adult's vocalization that is being imitated and not vice versa. The casual observations of mother–infant interactions in natural settings that have been reported (e.g. Lieberman, 1967) are not adequate to clarify who is imitating whom. One solution to this problem is to present taped or digitized models to infants in carefully controlled experimental settings. An alternative solution is to compare across experimental conditions to identify whose behaviour is changing during interaction. Another concern identified by Meltzoff & Moore (1983) is some control for spontaneous, non-imitative production of the target response. This is especially important in the case of vocal f_0, since mothers typically raise their vocal pitch into the infants' vocal pitch range during interactions. This results in an increased likelihood of coincidental pitch matching. Since none of the reports noted above took any of these concerns into account, we must consider these reports to be unsubstantiated until studies using appropriate experimental methodologies and controls have been done.

To examine these claims experimentally, Siegel, *et al.* (1990) attempted to corroborate the specific claim by Lieberman (1967) that infants differentially adjust their vocal pitch to match that of the parent (i.e. use higher pitch with mother than with father). They reported two experiments in which they recorded children at 0;8 to 0;9 (Experiment 1) or at 1;0 (Experiment 2) interacting with their parents. Acoustic analysis of the f_0 of the infants and their parents was performed. Comparisons were made between each adults' f_0 when speaking to their infant or to the experimenter and of the infants' f_0 when vocalizing with each of the parents. Although the results indicated that both parents raised their mean f_0 when speaking to their infant, there was no evidence that the INFANTS systematically used f_0 differentially with the two parents.

The failure of Siegel *et al.* to find any evidence of f_0 accommodation, however, could be due to the artificial nature of their recording sessions. Although made in the infant's home, the recording sessions were quite short (5–10 min in each condition) and did not involve spontaneous play sessions, but rather were interactions arranged specifically for the purpose of the study. This is a particular concern for two reasons. This short time may not have provided enough utterances to establish a reliable baseline for the infants' f_0, especially in the case of the infant-alone condition (Siegel *et al.* do not report the number of utterances in this condition). Insufficient data to establish a true baseline for the infants' f_0 when alone could lead to incorrect conclusions regarding the degree to which infants adjust their f_0 to their interactional partners. Furthermore, the presence of the experimenter during the recording sessions may have influenced the behaviour of both the parents and the infants.

Another potential problem is the age of the infants in the Siegel *et al.* study. Although the infants were of the same age as those reported by Lieberman (1967), other reports have suggested that pitch matching behaviour occurs at much younger ages (e.g. Lewis, 1936/1951; Papousek & Papousek, 1981). And Piaget (1951) reports quasi-imitative vocal behaviour as early as stage 2 sensorimotor development (ages 0;1 to 0;4). According to Piaget, infants at this stage are more likely to repeat one of their own habitual responses if someone mimics the baby immediately beforehand. Genuine imitation of within-repertoire vocalizations is stated to begin at stage 3 (ages 0;4 to 0;8).

The present study addresses these issues through a longitudinal case study. The advantages of following a single infant longitudinally are numerous. By having the parents record weekly in the infant's home we were able to capture spontaneous interactions with her parents and spontaneous non-social play (infant vocalizing alone). We were able to record longer sessions (15–20 min), increasing the likelihood of observing some form of pitch accommodation or imitation, should it occur only after an interaction has been ongoing for some time. Finally, because we recorded across a wide range of ages (0;2 to 1;6), we could look for developmental changes in the vocal interactions between the infant and parent *vis-à-vis* the emergence of different patterns of organization in her spontaneous vocalizations (see Oller, 1980; Stark, 1980). Specifically, we examined f_0 accommodation at specific stages in the infant's vocal development, with each stage representing the month in which the infant first began producing the utterance types of interest. These stages are described in terms of Oller's (1980) vocalization categories when relevant: (1) vocal play (0;3; Oller's Expansion Stage), characterized by fully-resonant nuclei (FRN's), marginal babbling (MB), and sounds such as raspberries, squeals, growls and yells; (2) reduplicated babbling (0;7; Oller's Canonical Babbling Stage) characterized by combinations of FRN's and consonant-like sounds combined into both reduplicated and non-reduplicated syllables; (3) variegated babbling (0;10; Oller's Variegated Babbling Stage) characterized by varied consonantal and vocalic types within multisyllabic strings; (4) single words (1;3); (5) two-word syntactic combinations (1;5). The latter two periods were included here, although they had not been tapped in prior studies, because we felt it was important to be able to examine any effect of language development on f_0 accommodation by the infant.

A secondary issue not addressed by the Siegel *et al.* study involves the pitch adjustments of the parents. While it is clear that both mothers and fathers increase their pitch when speaking to an infant relative to another adult (e.g. Fernald, Taeschner, Dunn, Papousek, de Boysson-Bardies & Fukui, 1989), the relative degree of adjustment by mothers and fathers and its developmental course have not been well studied. For example, in order to compare whether both parents adjust similarly in terms of their normal pitch range, it is important to have an appropriate baseline for comparison. The typical baseline used in previous studies has been the parents' pitch when speaking to the experimenter (e.g. Siegel *et al.*, 1990; cf. Fernald *et al.*, 1989). However, rather than a brief conversation with an unknown experimenter, a more appropriate baseline would be a lively, spontaneous conversation between the parents. This would be more likely to capture the natural pitch range of happy talk within a close relationship, comparable to the type of mother–infant interaction that has been examined in previous studies of dyadic communicative development in infancy. The present study provides just a parent–parent conversational baseline.

METHOD

Subjects

The subjects were a female infant (the second author's first born daughter) between the ages of 0;2 and 1;6, and her parents.

Recording sessions

Weekly tape recordings were made of the infant's vocalizations in spontaneous play interactions with each of her parents separately, and in isolated vocal play sessions. Each session lasted for 15–20 min. Also, for the adult–adult baseline a single conversation between the two parents of approximately 20 min duration was recorded when the infant was age 0;12. This lively conversation involved a variety of topics ranging from joking about a media blooper by a current political figure to an amusing anecdote about a mutual acquaintance. All sessions were recorded at the infant's home on a Sony TCD-5m cassette recorder with an Audio Technica unidirectional microphone (approximately 2–3 feet from the vocalizing subjects).

For the present investigation, these weekly recordings were sampled for sessions when the infant was 0;3, 0;7, 0;10, 1;3 and 1;5 in order to represent her behaviour during important transitions in vocal development (see introduction). For the infant in isolation, the sampling included all of her non-distress, non-vegetative, vocalic utterances. In the interactive play sessions, sampling of both infant and adult vocalizations was taken from those portions of each session during which vocal interactions occurred between the infant and the parent. Thus, portions of sessions during which the infant was silent during long stretches of time were not sampled. Utterances were identified based on complete breath groups (see Lieberman, 1967). A minimum of 25 utterances from each conversational partner was selected at each month. If the minimum number of utterances could not be obtained from a single session, additional utterances were sampled from the following week's session.[1] Utterances were excluded if the two conversational partners' speech overlapped, background noise interfered with analysis, or if voice quality precluded analysis (e.g. high degrees of creaky voice, or whispered speech).

Acoustic analysis

Utterances selected for analysis were digitized at a rate of 10 KHz and stored on disk using a Vax 11-780 computer at Haskins Laboratories. Fundamental-frequency analysis was performed using an autocorrelation algorithm which estimated the f_0 value for each 10 millisecond window with 50% overlap between successive windows (Interactive Laboratory Systems analysis programme: Signal Technologies, Inc., 1989). The mean f_0 of each utterance was computed by summing over all analysis windows with non-zero values and dividing by the number of non-zero windows. The results of the acoustic analysis were verified for a randomly selected subset of utterances (5% of the total) by displaying the waveforms on a high resolution computer display and directly measuring the period of each glottal pulse. The correlation between mean f_0 computed by this method and by the autocorrelation analysis was 0·90.

[1] There were two exceptions to the minimum of 25 utterances per speaker at each age. One exception was for the infant alone at age 0;7, where only eight utterances were included. The infant was particularly quiet during this session, but produced the minimum number of vocalizations during the interactive sessions of the same week. Rather than sample from the next week just for the infant alone session, we accepted the small number of utterances produced in this session. In the second exception, the mother produced only 23 analysable utterances when the infant was 0;3. Since both the infant and the father produced the minimum number of utterances at this week, we decided not to go to the next week just to add two utterances for the mother.

RESULTS

Unweighted and weighted means for each speaker in each age × interactional condition (i.e. isolation, with mother and with father) are presented in Table 1. Unweighted means were computed for each utterance in each age × interactional condition by averaging across all non-zero analysis frames and dividing by the number of frames. Weighted means were computed by multiplying the unweighted means for each utterance in each age × interactional condition by its duration. The sum of these f_0-duration cross-products was then divided by the mean duration of the utterances. This resulted in a single mean weighted f_0 value for each cell in the age × condition and age × speaker matrices. The weighted means were calculated to cir-

TABLE 1. *Weighted and unweighted mean f_0 for each speaker in each condition*

Speaker/condition	Infant age				
	0;3	0;7	0;10	1;3	1;5
Infant alone					
Weighted mean	349	398	350	299	333
Unweighted mean	389	465	366	315	324
	(29)	(8)	(58)	(52)	(76)
Infant w/mother					
Weighted mean	343	373	297	321	270
Unweighted mean	341	401	342	355	320
	(30)	(25)	(31)	(44)	(37)
Infant w/father					
Weighted mean	340	365	333	307	311
Unweighted mean	341	395	358	319	338
	(25)	(25)	(34)	(31)	(30)
Mother w/infant					
Weighted mean	347	291	239	254	228
Unweighted mean	344	339	262	285	274
	(23)	(61)	(52)	(37)	(27)
Father w/infant					
Weighted mean	120	162	159	127	126
Unweighted mean	132	167	149	128	122
	(29)	(48)	(30)	(32)	(37)
Mother w/father	1;0				
Weighted mean	211				
Unweighted	212				
Father w/mother					
Weighted mean	105				
Unweighted	105				

( ) = the number of observations in each cell for the unweighted analysis.

cumvent the possibility of biasing that might result from any correlation between utterance duration and f_0 in the adults' or infant's vocalizations.[2] In general, when differences are seen between the two computations, the unweighted means tend to be somewhat higher than the weighted means (i.e. are biased by the tendency of higher f_0 for brief utterances). Analyses of variance were performed on each data set to compare: (1) the parents' mean f_0 when conversing with each other; (2) the parents' mean f_0 at each age when interacting with the infant; (3) infant mean f_0 at each age and interactional condition. Only the results for the unweighted means are presented, since the weighted means gave the same results in all but one case and interaction terms (e.g. age × speaker) could not be tested with the weighted means because there was only a single data point in each cell of the relevant matrix.

Parents' mean f_0

When conversing with each other, the mother and father had unweighted mean f_0's of 212 and 105 Hz, respectively. These are very close to mean f_0 values reported for females and males using adult-directed speech published in other studies. For example, Fernald *et al.* (1989) reported means for American female and male parents of 206 and 105 Hz, respectively. The weighted mean f_0's of the mother and father were 211 and 105 Hz, respectively. That is, the parents showed no tendency toward a systematic relation between f_0 and length of utterance in adult–adult speech.

In order to verify that the parents' mean f_0's differed when interacting with the infant, a 5 (age) × 2 (speaker) ANOVA was performed on the parents' unweighted mean f_0 data. This analysis revealed significant main effects of age ($F(4, 366) = 5.58$; $p < 0.0001$)[3] and speaker ($F(1, 366) = 260.88$; $p < 0.0001$), and a significant age × speaker interaction ($F(4, 366) = 2.40$; $p < 0.05$). Separate ANOVAs comparing the mean f_0 of the two speakers at each age indicated that the speakers differed significantly at each of the five ages (all p's < 0.001). Separate ANOVAs were performed comparing each speaker's mean f_0 across ages. This analysis on the mother's mean f_0 indicated a main effect of age ($F(4, 195) = 4.06$; $p < 0.01$), suggesting she used somewhat higher f_0 when the infant was young (e.g. 0;3 and 0;7) than later in the infant's development. However, pairwise comparisons (Scheffe's F-test) indicated no significant differences between ages. For the father, a significant main effect of age was also noted ($F(4, 171) = 9.79$; $p < 0.001$). Pair-wise comparisons (Scheffe's F-test) indicated that the mean f_0 age 0;7

[2] Specifically, for the infant, and to some degree for the mother in ID speech only, longer utterances showed some tendency toward lower mean f_0 than did shorter utterances. Across ages and conditions, correlations between duration and f_0 in the infant's vocalizations ranged from $r = 0.10$ to $r = -0.32$.

[3] Age was not significant in the weighted means analysis, probably because of the reduced degrees of freedom.

(167 Hz) was higher than each of the means at ages 0;3 (132 Hz), 1;3 (149 Hz) and 1;5 (128 Hz) (all p's $< 0{\cdot}01$). Thus, the age × speaker interaction appears to reflect the fact that the father's mean f_0 differed nonlinearly as a function of the infant's age, while the mother's mean f_0 varied in a more linear fashion over age.

A final set of analyses assessed the minimum difference between the adult-directed (AD) and infant-directed (ID) f_0 for each parent. Thus, t-tests were used to compare the father's AD unweighted mean f_0 (105 Hz) with his ID unweighted f_0 at 0;17 (122 Hz), and the mother's AD unweighted mean f_0 (212 Hz) with her ID unweighted mean at 0;10 (262 Hz). These analyses indicated that both comparisons were significant (p's $< 0{\cdot}01$), indicating that both parents significantly raised their f_0 when interacting with the infant even at the ages for which they showed the smallest magnitude of mean f_0 difference between ID and AD speech.

Infants' mean f_0

Differences in the infants' unweighted mean f_0 across ages and conditions were quite modest, ranging from 315 Hz at 1;3 when alone to 465 Hz at 0;7 when alone. The infant's mean f_0 was highest at 0;7 in each condition (the same age at which the father's mean unweighted f_0 was highest). In order to investigate the main question of the study, whether the infant adjusted her f_0 differentially when interacting with her parents, a 5 (age) × 3 (condition) ANOVA was performed on the infant's unweighted mean f_0. This analysis indicated a significant main effect for age ($F(4, 520) = 6{\cdot}85$; $p < 0{\cdot}001$). The effect of condition was not significant ($p > 0{\cdot}20$), nor was the age × condition interaction ($p > 0{\cdot}20$). Pairwise comparisons of the infant's mean f_0 at each age, collapsed across condition, indicated that the mean f_0 at 0;7 (407 Hz) was greater than the means at 1;3 (330 Hz) and 1;5 (326 Hz), reflecting a general downward trend in the infant's mean f_0 with age, consistent with other reports of age changes in infant f_0 (e.g. Kent & Murray, 1982; Murray & Murray, 1980; Robb, Saxman & Grant, 1989).

In summary, these analyses indicate that both the mother and father significantly increased their mean f_0 when interacting with the infant over their adult-direct mean f_0. The infant, on the other hand, did not significantly alter her mean f_0 when interacting with her parents compared to her mean f_0 when alone, nor did she use a different f_0 toward her mother than toward her father.

Time series of infant and adult utterances

One possible reason for the failure to find evidence of infant f_0 accommodation in our data and Siegel *et al.*'s data is that the phenomenon might only occur during specific parts of a session, such as when the infant is most engaged in the social interaction. If this is the case, we may have

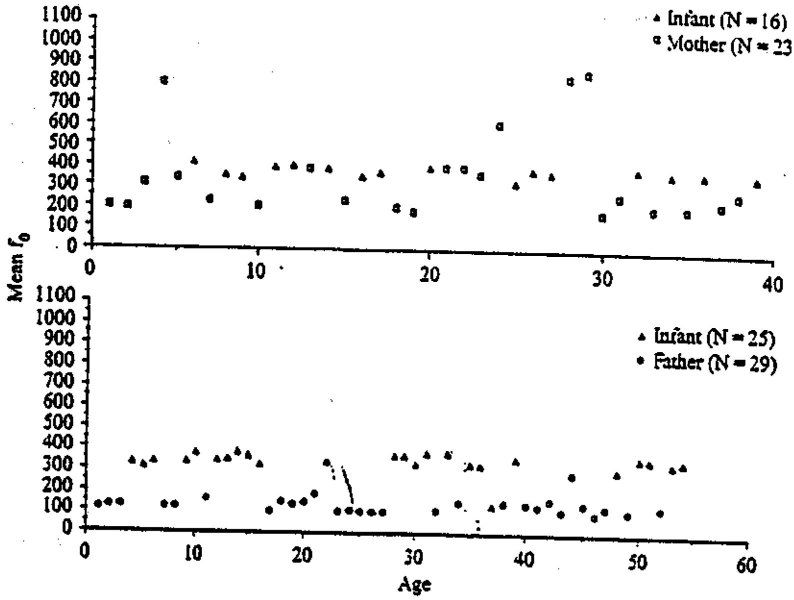

Fig. 1. Time series plot of mother and infant and father and infant mean f_0 at age 0;3.

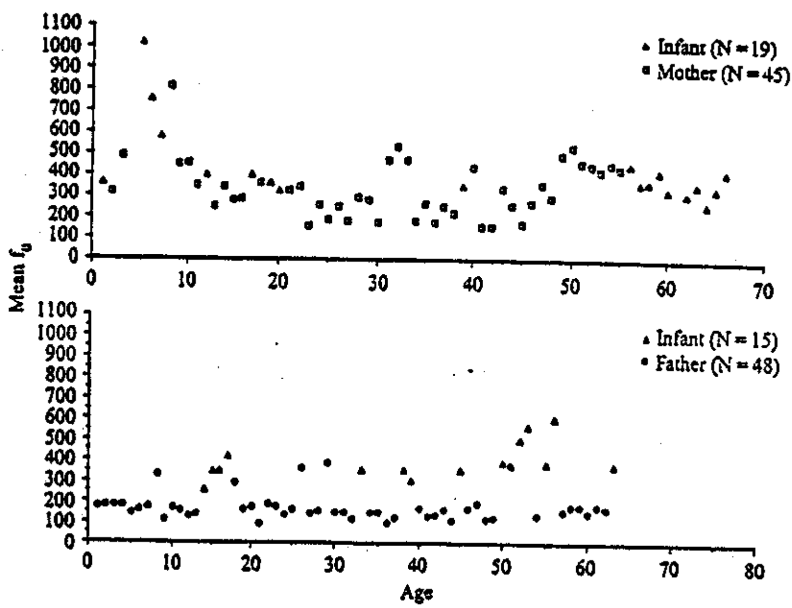

Fig. 2. Time series plot of mother and infant and father and infant mean f_0 at age 0;7.

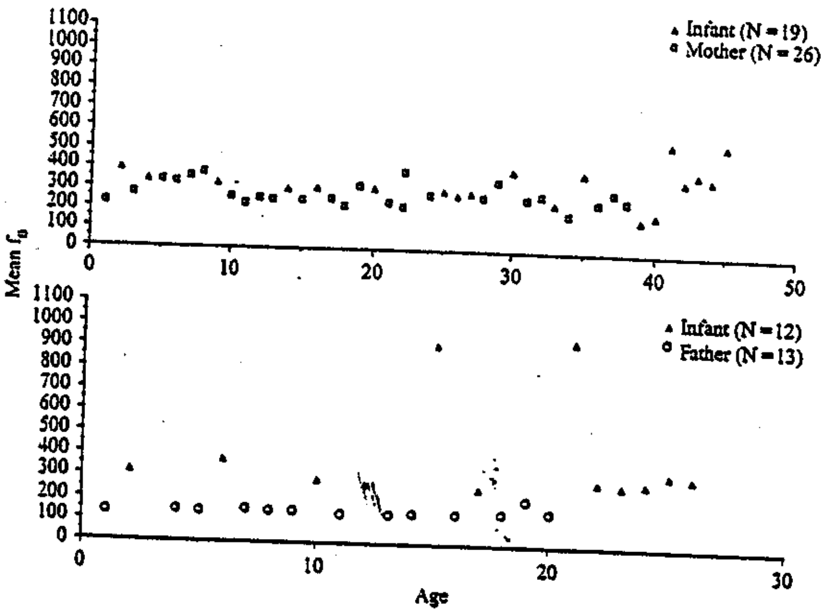

Fig. 3. Time series plot of mother and infant and father and infant mean f_0 at age 0;10.

obscured any evidence of the effect by averaging episodes of high dyadic engagement with episodes when the infant was less engaged. To investigate this possibility, we selected portions of each session for a finer-grained analysis. For each session, we chose a contiguous temporal region that contained the greatest degree of vocal exchange (operationalized as vocal turn-taking) between the parent and infant. We thus eliminated regions where only the infant or the parent vocalized uninterrupted for an extended period. For these subsets, we then plotted the temporal sequence of the mean f_0 of each speakers' utterances. These data are presented in Figures 1–5. Evidence for the presence of f_0 adjustment or imitation would be seen as a tendency for the mean f_0 of the infant's utterances to be very near to the mean f_0 of the preceding parent's utterance, and to rise and fall in tandem with changes in the adult f_0. As can be seen in the figures, this rarely happened, even in the portions of the session involving the highest degree of turntaking. Despite the low resolution of the figures, due to the wide f_0 range, changes in the infant's f_0 are almost always temporally offset from changes in the parents' f_0. Thus, although there is an occasional approximation of f_0 values between the mother and the infant, there is no tendency for this to happen more often for infant utterances that follow the mother's utterances than for those that precede it.

The large range on the ordinates of Figs 1–5 was needed to accommodate

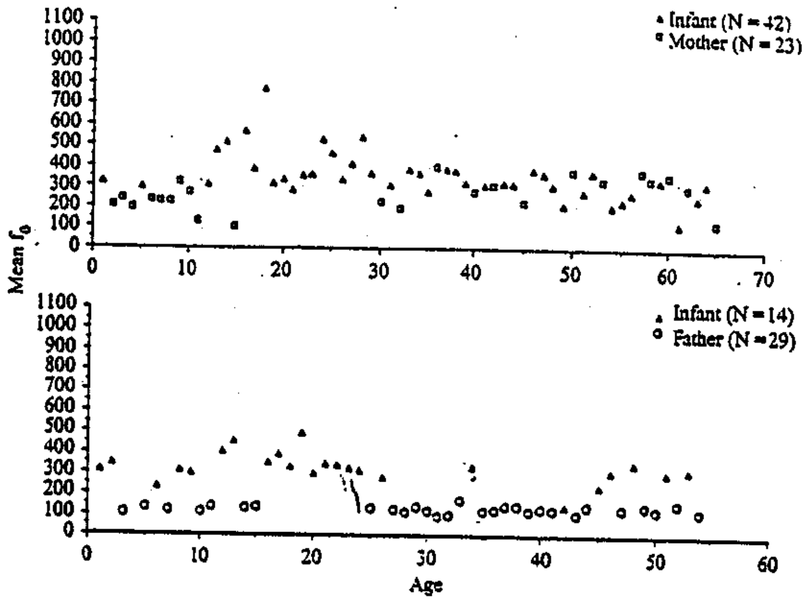

Fig. 4. Time series plot of mother and infant and father and infant mean f_0 at age 1;3.

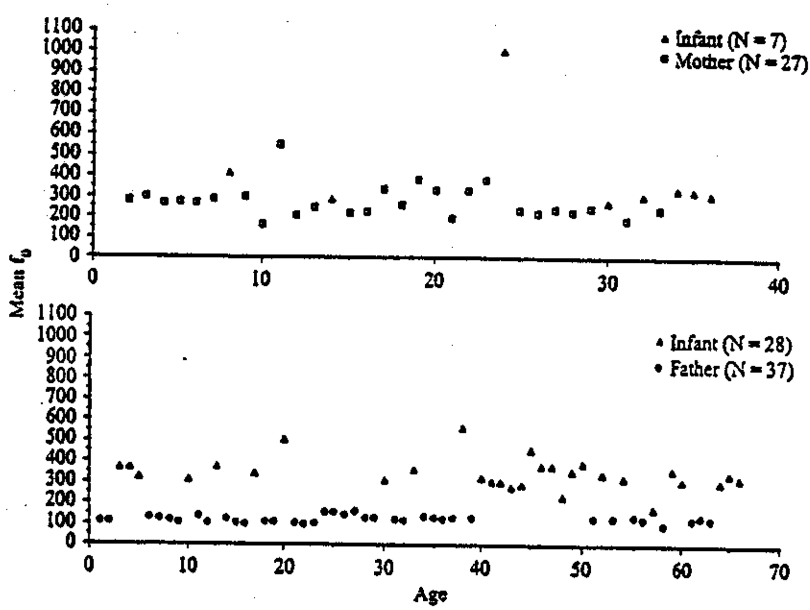

Fig. 5. Time series plot of mother and infant and father and infant mean f_0 at age of 1;5.

the wide f_0 range of the infant. Unfortunately, this often makes it difficult to determine how similar the plotted mean f_0 values of the two speakers are, especially in the mother–infant interactions. Therefore, Fig. 6 presents two

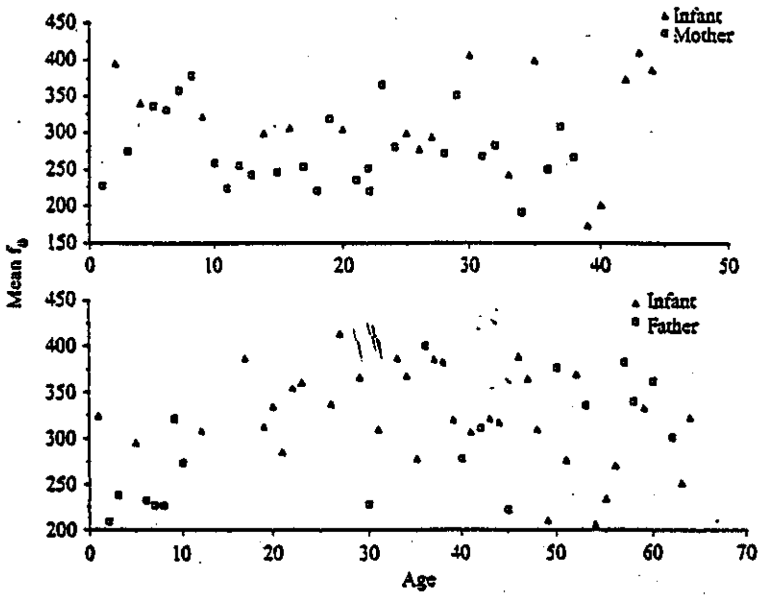

Fig. 6. Time series plot of mother and infant mean f_0 at ages 0;10 (top) and 1;3 (bottom) with increased f_0 resolution.

of the mother–infant time series plots with reduced range on the ordinate. These higher resolution figures make two points clear. First, many of the points that appear to be quite close in mean f_0 in the original figures are in fact 50–100 Hz apart, and would thus be unlikely candidates for imitation or accommodation. Secondly, when an infant vocalization follows one of the mother's vocalizations and is close in mean f_0, there are often earlier infant vocalizations in the same f_0 range. This is consistent with our interpretation that it is the mother's f_0 that is adjusted into the infant's range, or that the two speakers occasionally have coincidentally similar f_0 values on adjacent vocalizations. Both of these occurrences need to be distinguished from true infant imitation or accommodation of adult mean f_0.

F_0-*ratios*

One observation that comes from Figs 1–5 is that there appears to be an approximately constant ratio of infant to parent mean f_0 values overall. For the infant and her mother, this appears to be nearly 1:1 for at least some ages (e.g. 0;10 and 1;3) when most of the mother's and infant's mean f_0 values are in the same range. However, the father's f_0 and the infant's f_0 seldom overlap. Despite this, there appears to be a tendency for the infant and her father to also maintain a fixed relation between their mean f_0. To quantify this tendency, we calculated ratios between the mean f_0 of the infant and each of her parents (see Table 2). These ratios confirm the impression from the

TABLE 2. *Parent/infant and parent/parent mean f_0 ratios*

Speakers	Infant age				
	0;3	0;7	0;10	1;3	1;5
Mother w/infant	1·0	1·2	1·3	1·2	1·2
Father w/infant	2·6	2·4	2·4	2·5	2·8
Mother w/father	1·6	1·4	1·1	1·2	1·1
Father w/mother	1·1	1·5	1·5	1·2	1·2

figures (although the ratios contain all of the utterances from each condition). The ratio between the infant and mother's mean f_0 varies from 1·0 to 1·3 across ages, while for the infant and her father, the ratios range from 2·4 to 2·8. Since both the parents' and the infant's mean f_0 change across ages, the consistency of these ratio values is probably not simply an artifact. Rather, these ratios probably reflect either a mutual attempt to maintain a consistent relation between mean f_0 of the interactants, or an attempt primarily by the parents to do so. Evidence that both parents systematically maintained a higher mean f_0 when interacting with the infant than during adult–adult conversation is also provided in Table 2, which shows ratios between the parents' mean f_0 for the adult–adult interaction and for adult–infant interactions at each age. These ratios suggest that the parents increased their mean f_0 approximately equally, relative to their adult–adult levels, but that the infant did not systematically lower her f_0 toward either parents' f_0 relative to her mean f_0 produced in isolation.

DISCUSSION

The goal of this investigation was to explore reports that infants spontaneously imitate the vocal f_0 of their adult caregivers or accommodate their own f_0 toward that of each parent. We found no evidence that the infant in this study made differential changes in voice pitch when interacting with her parents. Despite consistent differences in the mean f_0 between the two parents of approximately one octave when interacting with the infant, differences in the infant's mean f_0 across conditions never exceeded 40 Hz and followed no consistent pattern with respect to condition. This was true for both weighted and unweighted f_0 measures. Thus, our analyses of mean

f_0 provide no statistical support for the claim that infants spontaneously accommodate their f_0 differentially towards that of adult interactants. Rather, we found strong evidence that the parents adjusted their pitch to accommodate to the infant's f_0.

Despite our failure to find mean f_0 differences that support the notion of f_0 adjustment, we pursued two other approaches in our data, one a finer-grained analysis, the other a more global analysis. Neither of these analyses provided support for the claim that the infant adjusted her mean f_0 towards that of her parents. Our failure to find evidence for vocal f_0 accommodation between an infant and her parents in a longitudinal study is compatible with the findings of Siegel *et al.* (1990), who failed to find evidence for accommodation in a cross-sectional study at just two ages.

One possible reason the lack of f_0 accommodation might have been that the infant in our study was not within the normal range of infant mean f_0 values. However, this was not the case. For example, Kent & Murray (1982) report various acoustic measurements on three groups of infants at ages 0;3, 0;6 and 0;9. Mean f_0 values of individual infants at these ages were typically between 350 and 500 Hz. With respect to mean f_0 across subjects, they report values of 445 Hz, 450 Hz, and 415 Hz at ages 0;3, 0;6 and 0;9, respectively. Similar values have been reported by Murray & Murray (1980). Our infant's mean f_0 at ages 0;3, 0;7 and 0;10 when alone was 389, 465 and 366 Hz, respectively, easily within the range of individual means reported by Kent & Murray (1982).

Robb, Saxman & Grant (1989) report mean f_0 for seven infants recorded longitudinally. These infants were recorded while interacting with a parent or the experimenter, so the values should be very comparable to our data from interactional conditions. Data is presented for three infants at age 0;8 with a combined mean of 430 Hz and individual means ranging from 293–642 Hz. At age 0;10, mean f_0 for the same three infants was 396 Hz, with individual means ranging from 346–430 Hz. Robb *et al.* also reported data for six infants at age 1;3 (mean = 423 Hz, range = 299–553 Hz) and seven infants at age 1;5 (mean = 320, range = 291–423 Hz). From the data in Table 1, it is clear that the infant in this study had mean f_0 values that are well within the range of individual variation reported by these studies.

Another possible reason for failure to find accommodation of f_0 would be if the infant was generally reluctant to imitate speech. Based on informal observations by her mother (author CB), she was willing and able to imitate known lexical items and unknown/nonsense segmental strings upon request by at least ages 1;2 to 1;3. Moreover, in a separate study, a large corpus of such imitations was recorded at ages 1;7 to 1;10. Acoustic and phonetic analysis confirms that these were indeed imitations (Best, 1994). Even more directly relevant to the age range in the present study, other recordings of this infant indicate imitation of vowels and CV's (presented as targets with multiple repetitions in a controlled situation) by ages 0;8 to 0;9, an observation consistent with Piaget's claims that voluntary imitation begins by about age 0;8 (Piaget, 1951).

One positive finding from this study was a tendency for the infant and her parents to maintain an approximately constant ratio between their respective f_0's across sessions. For the father and infant, this ratio was between 2·4–2·8, while for the mother and infant, this ratio was between 1·0–1·3. The tendency to maintain these ratios occurred despite the fact that both infant and parent mean f_0 changed significantly across sessions. Given the lack of infant f_0 accommodation towards the mother's versus the father's f_0 during interactions, and the fact that these ratios vary more as a function of changes in the parents' mean f_0 than the infant's (Table 1; figs 1–5), it appears that the relatively narrow range is the result of adjustments in the parents' mean f_0. For example, the two largest ratios for the father are at 0;3 and 1;5 (ratios = 2·8 and 2·6, respectively). At these times, the father's mean f_0 was 132 and 122 while the infant's mean f_0 was 341 and 338, respectively.

A major limitation of our study is that it involves a single subject. If our result was the only data available besides Lieberman and his colleagues reports, we would need to be cautious in our conclusions. However, given our results and Siegel *et al.*'s results, systematic experimental studies, both cross-sectional and longitudinal, have failed to find evidence favouring infants' tendency to accommodate mean f_0 differentially toward that of male versus female adult conversational partners. Thus, it would appear that infants do not imitate or accommodate average f_0 of their parents. In spite of these failures with mean f_0, we do not rule out the possibility that other aspects of vocal behaviour might be imitated by infants. Indeed, Kuhl & Meltzoff (1988) present data suggesting that infants imitate vowel and pitch contour targets presented in controlled laboratory situations.

How, then, can one account for earlier claims of such a phenomenon (e.g. Lieberman, 1967)? The answer to this question may reside in the nature of those reports, i.e. the small number of observations, lack of systematic comparisons of situational variables, and inadequate control of other potential sources of influence. The data presented here suggest that the most likely explanation is that the parents adjusted their vocal pitch into the range of their infants' vocal pitch and that the observations noted are coincidences based on the natural variations of two speakers vocalizing within the same pitch range. Alternatively, or in addition to this, it may be that the apparent f_0 imitation by the infants observed in earlier reports was the result of PARENTS' inadvertently 'training' pitch imitation by their infants, given evidence that such training can be easily accomplished by age 0;6 (Kessen, Levine & Wendrich, 1979). Alternatively, the parents' interaction styles may have differed. For example, the mothers may have tended to cause higher levels of excitement in their infants than fathers did, thus AFFECTIVELY raising the infants' vocal pitch level more to mothers than to fathers. In the latter situation, the infants' higher pitch could not be considered imitation.

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