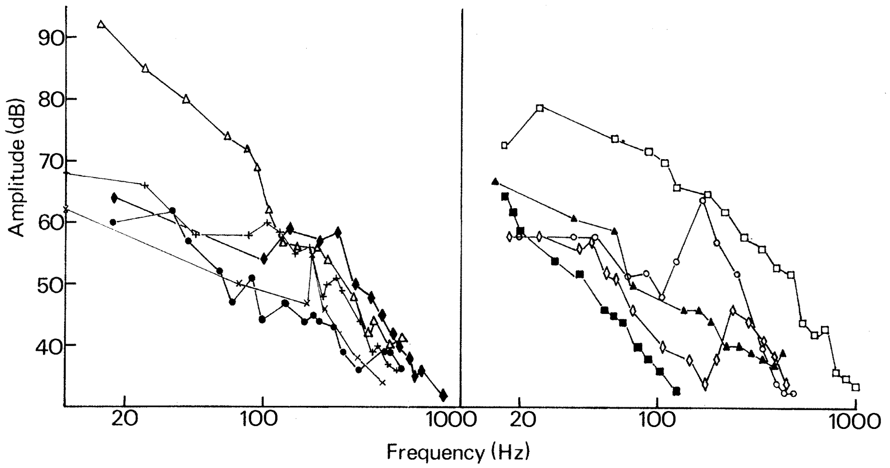

Fig. 2. Root mean square values at peaks from spectrum analyses for different types of internal sound: ○, gurgle; ●, swallow; △, blowing; ▲, chewing cud; □, rushing noise; ■, quiet ewe; ×, intestinal noise; +, eating hay; ◇, drinking; ◆, eating nuts.

it was reduced below and above this frequency and at higher frequencies remained at about 20 dB up to the highest recorded, 5 kHz. The amount of attenuation fluctuated, however: conversation at normal levels outside the animal could often, but not always, be understood when transmitted from inside. Raised voices were almost always distinct.

Sounds generated within the ewe herself were picked up by the implanted hydrophone, amplified, and recorded by a tape recorder or fed directly to the spectrum analyzer (as the amplifier had two outputs we were able to listen while analyzing the sounds). In the main, sounds heard were characteristic and identifiable: drinking, eating, swallowing, rumination, and sometimes heavy breathing could be heard. Rumination, unexpectedly, was rather quiet. A rushing sound sometimes accompanied movement by the ewe and irregular gurgles, probably of digestive origin, occurred frequently. Periods of quiet were not unusual. Figure 2 shows root mean square values at peaks taken from spectrum analyses, for different types of internal sound. These were of low frequency, tailing off above 500 Hz.

Although we found attenuation of external sounds to be less than in other species (*2*, *3*, *6*), the loudness peaks and frequency of internal sounds were similar to those recorded by others (*3*, *6*). However, average sound levels were lower than those previously reported (*2*, *3*, *6*, *7*), especially as we often observed periods of quiet. In one particular our results were at variance with those of other workers: we were not able to hear sounds from the maternal cardiovascular system. By holding a hydrophone firmly against the ewe's skin in the brachial area we were able to pick up heart sounds from outside the animal without being able to hear the reported pulsations from inside. It is possible, and consistent with spectrum analyses, that these sounds occur at very low frequencies and, when attenuated, are below the human threshold for sound.

Our results suggest that sounds available to the sheep fetus, within its normal fluid environment, are varied and of rather low frequency when they are generated by, or within, the mother. External sounds are attenuated by about 16 to 37 dB, most attenuation occurring at frequencies around 1 kHz. In the sheep, external sounds of above 65 dB at the body wall should often penetrate to the uterus.

The extent to which sound signals inside the amniotic sac are heard by the fetus is another question currently being explored; in precocial mammals, the auditory system is believed to become functional well before birth, and there is evidence for this in the sheep after day 100 of gestation (*8*, *9*). A further question concerns the efficiency of the hearing mechanism within a totally fluid environment; the mammalian fetus is known to move in response to sound from outside the mother (*10*), and in the guinea pig, prenatal exposure to a specific sound changes the neonate's response to the sound (*11*).

Implications for the human fetus are not clear because of postural, placental, and other anatomical differences. The main difference between results of research with the goat (*7*) and ours can be attributed to our use of a method of greater physiological validity, namely, recording from inside the intact amnion in the fetus's normal fluid environment. We suggest that the auditory experience of the fetal mammal may be considerably more extensive, more varied, and, as in birds, possibly of greater postnatal significance than has been believed.

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Of Human Bonding: Newborns Prefer Their Mothers' Voices

Abstract. *By sucking on a nonnutritive nipple in different ways, a newborn human could produce either its mother's voice or the voice of another female. Infants learned how to produce the mother's voice and produced it more often than the other voice. The neonate's preference for the maternal voice suggests that the period shortly after birth may be important for initiating infant bonding to the mother.*

Human responsiveness to sound begins in the third trimester of life and by birth reaches sophisticated levels (*1*), especially with respect to speech (*2*). Early auditory competency probably subserves a variety of developmental functions such as language acquisition (*1*, *3*) and mother-infant bonding (*4*, *5*). Mother-infant bonding would best be served by (and may even require) the ability of a newborn to discriminate its mother's voice from that of other females. However, evidence for differential sensitivity to or discrimination of the maternal voice is available only for older infants for whom the bonding process is well advanced (*6*). Therefore, the role of maternal voice discrimination in formation of the mother-infant bond is unclear. If the newborn's sensitivities to

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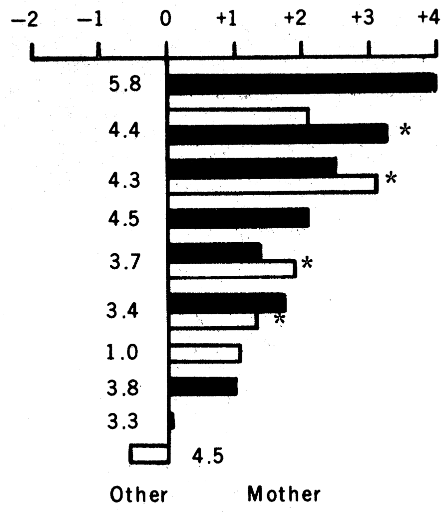

Fig. 1. For each subject, signed difference scores between the median IBI's without vocal feedback (baseline) and with differential vocal feedback (session 1). Differences of the four reversal sessions (*) are based on medians with differential feedback in sessions 1 and 2. Positive values indicate a preference for the maternal voice and negative values a preference for the nonmaternal voice. Filled bars indicate that the mother's voice followed IBI's of less than the baseline median; open bars indicate that her voice followed intervals equal to or greater than the median. Median IBI's of the baseline (in seconds) are shown opposite the bars.

speech subserves bonding, discrimination of and preference for the maternal voice should be evident near birth. We now report that a newborn infant younger than 3 days of age can not only discriminate its mother's voice but also will work to produce her voice in preference to the voice of another female.

The subjects were ten Caucasian neonates (five male and five female) (*7*). Shortly after delivery we tape-recorded the voices of mothers of infants selected for testing as they read Dr. Seuss's *To Think That I Saw It On Mulberry Street.* Recordings were edited to provide 25 minutes of uninterrupted prose, and testing of whether infants would differentially produce their mothers' voices began within 24 hours of recording. Sessions began by coaxing the infant to a state of quiet alertness (*8*). The infant was then placed supine in its basinette, earphones were secured over its ears, and a nonnutritive nipple was placed in its mouth. An assistant held the nipple loosely in place; she was unaware of the experimental condition of the individual infant and could neither hear the tapes nor be seen by the infant. The nipple was connected, by way of a pressure transducer, to the solid-state programming and recording equipment. The infants were then allowed 2 minutes to adjust to the situation. Sucking activity was recorded during the next 5 minutes, but voices were never presented. This baseline period was used to determine the median interburst interval (IBI) or time elapsing between the end of one burst of sucking and the beginning of the next (*9*). A burst was defined as a series of individual sucks separated from one another by less than 2 seconds. Testing with the voices began after the baseline had been established.

For five randomly selected infants, sucking burst terminating IBI's equal to or greater than the baseline median (*t*) produced only his or her mother's voice ($\mathrm{IBI} \geq t$), and bursts terminating intervals less than the median produced only the voice of another infant's mother (*10*). Thus, only one of the voices was presented, stereophonically, with the first suck of a burst and remained on until the burst ended, that is, until 2 seconds elapsed without a suck. For the other five infants, the conditions were reversed. Testing lasted 20 minutes.

A preference for the maternal voice was indicated if the infant produced it more often than the nonmaternal voice. However, unequal frequencies not indicative of preference for the maternal voice per se could result either because short (or long) IBI's were easier to produce or because the acoustic qualities of a particular voice, such as pitch or intensity, rendered it a more effective form of feedback. The effects of response requirements and voice characteristics were controlled (i) by requiring half the infants to respond after short IBI's to produce the mother's voice and half to respond after long ones and (ii) by having each maternal voice also serve as the nonmaternal voice for another infant.

Preference for the mother's voice was shown by the increase in the proportion of IBI's capable of producing her voice; the median IBI's shifted from their baseline values in a direction that produced the maternal voice more than half the time. Eight of the ten medians were shifted in a direction of the maternal voice (mean = 1.90 seconds, a 34 percent increase) (sign test, $P = .02$), one shifted in the direction that produced the nonmaternal voice more often, and one median did not change from its baseline value (Fig. 1).

If these infants were working to gain access to their mother's voice, reversing the response requirements should result in a reversal of their IBI's. Four infants, two from each condition, who produced their mother's voice more often in session 1 were able to complete a second session 24 hours later, in which the response requirements were reversed (*11*).

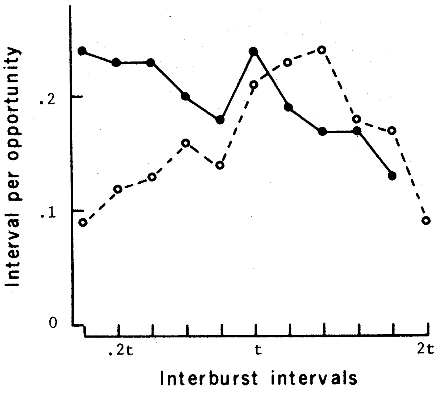

Fig. 2. Interburst interval per opportunity when the maternal voice followed intervals less than the baseline median (solid line) and intervals equal to or greater than the median (dashed line). The IBI's are represented on the abscissa by the lower bound of interval classes equal to one-fifth the baseline median (*t*).

Differential feedback in session 2 began immediately after the 2-minute adjustment period. The criterion time remained equal to the baseline median of the first session. For all four infants, the median IBI's shifted toward the new criterion values and away from those which previously produced the maternal voice. The average magnitude of the difference between the medians of the first and reversal sessions was 1.95 seconds.

Apparently the infant learned to gain access to the mother's voice. Since specific temporal properties of sucking were required to produce the maternal voice, we sought evidence for the acquisition of temporally differentiated responding. Temporal discrimination within each condition was ascertained by constructing the function for IBI per opportunity: IBI's were collected into classes equal to one-fifth the baseline median, and the frequency of each class was divided by the total frequency of classes having equal and larger values (*12*). When IBI's less than the baseline median were required, the likelihood of terminating interburst intervals was highest for classes less than the median (Fig. 2), whereas when longer intervals were required, the probability of terminating an IBI was maximal for intervals slightly longer than the median. Feedback from the maternal voice effectively differentiated the temporal character of responding that produced it: the probability of terminating IBI's was highest when termination resulted in the maternal voice.

Repeating the experiment with 16 female neonates and a different discrimination procedure confirmed their preference for the maternal voice (*13*). The discriminative stimuli were a 400-Hz tone of 4 seconds duration (tone) and a 4-second period of silence (no tone). Each IBI contained an alternating sequence of tone–no-tone periods, and each stimulus was equally likely to begin a sequence. For eight infants, a sucking burst initiated during a tone period turned off the tone and produced the Dr. Seuss story read by the infant's mother, whereas sucking bursts during a no-tone period produced the nonmaternal voice. The elicited voice remained until the sucking burst ended, at which time the tone–no-tone alternation began anew. The discriminative stimuli were reversed for the other eight neonates. Testing with the voices began immediately after the 2-minute adjustment period and lasted 20 minutes. Each maternal voice also served as a nonmaternal voice.

During the first third of the testing session, the infants were as likely to suck during a stimulus period correlated with the maternal voice as during one correlated with the nonmaternal voice (Table 1). However, in the last third of the session the infants sucked during stimulus periods associated with their mother's voice approximately 24 percent more often than during those associated with the nonmaternal voice, a significant increase [$F(1, 14) = 8.97$, $P < .01$]. Thus, at the beginning of testing there was no indication of stimulus discrimination or voice preference. By the end of the 20-minute session, feedback from the maternal voice produced clear evidence of an auditory discrimination; the probability of sucking during tone and no-tone periods was greater when sucking produced the maternal voice.

The infants in these studies lived in a group nursery; their general care and night feedings were handled by a number of female nursery personnel. They were fed in their mothers' rooms by their mothers at 9:30 a.m. and at 1:30, 5:00, and 8:30 p.m. At most, they had 12 hours of postnatal contact with their mothers before testing. Similarly reared infants prefer the human voice to other acoustically complex stimuli (*14*). But, as our data show, newborns reared in group nurseries that allow minimal maternal contact can also discriminate between their mothers and other speakers and, moreover, will work to produce their mothers' voices in preference to those of other females. Thus, within the first 3 days of postnatal development, newborns prefer the human voice, discriminate between speakers, and demonstrate a preference for their mothers' voices with only limited maternal exposure.

The neonate's capacity to rapidly acquire a stimulus discrimination that controls behavior (*15*) could provide the means by which limited postnatal experience with the mother results in preference for her voice. The early preference demonstrated here is possible because newborns have auditory competencies adequate for discriminating individual speakers: they are sensitive to rhythmicity (*16*), intonation (*17*), frequency variation (*1, 13*), and phonetic components of speech (*18*). Their general sensory competency may enable other maternal cues, such as her odor (*19*) and the manner in which she handles her infant (*20*), to serve as supporting bases for discrimination and vocal preference. Prenatal (intrauterine) auditory experience may also be a factor. Although the significance and nature of intrauterine auditory experience in humans is not known, perceptual preferences and proximity-seeking responses of some infrahuman infants are profoundly affected by auditory experience before birth (*21*).

Table 1. Mean ($\bar{X}$) and standard deviation (S.D.) of the relative frequency of sucking during a stimulus associated with the maternal voice divided by the relative frequency of sucking during a stimulus associated with the nonmaternal voice. A ratio of 1.0 indicates no preference.

Stimulus associated with maternal voice	First third		Last third	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Tone	0.97	.33	1.26	.33
No tone	1.04	.31	1.22	.19
Combined	1.00	.32	1.24	.27

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7. The infants were randomly selected from those meeting the following criteria: (i) gestation, full term; (ii) delivery, uncomplicated; (iii) birth weight, between 2500 and 3850 grams; and (iv) APGAR score, at least eight at 1 and 5 minutes after birth. If circumsized, males were not observed until at least 12 hours afterward. Informed written consent was obtained from the mother, and she was invited to observe the testing procedure. Testing sessions began between 2.5 and 3.5 hours after the 6 a.m. or 12 p.m. feeding. All infants were bottle-fed.
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9. With quiet and alert newborns, nonnutritive sucking typically occurs as bursts of individual sucks, each separated by a second or so, while the bursts themselves are separated by several seconds or more. Interburst intervals tend to be unimodally distributed with modal values differing among infants. [K. Kaye, in *Studies in Mother-Infant Interaction*, H. R. Schaffer, Ed. (Academic Press, New York, 1977)]. A suck was said to occur when the negative pressure exerted on the nipple reached 20 mm-Hg. This value is almost always exceeded during nonnutritive sucking by healthy infants, but is virtually never produced by nonsucking mouth movement.
10. The tape reels revolved continuously, and one or the other of the voices was electronically switched to the earphones when the response threshold was met. Because the thresholds were detected electronically, voice onset occurred at the moment the negative pressure reached 20 mm-Hg.
11. Two infants were not tested a second time, because we could not gain access to the testing room, which served as an auxillary nursery and as an isolation room. The sessions of two infants who cried were terminated. Two other infants were tested a second time, but in their first session one had shown no preference and the other had shown only a slight preference for the nonmaternal voice. Their performance may have been affected by inconsistent feedback. Because their peak sucking pressures were near the threshold of the apparatus, very similar sucks would sometimes produce feedback and sometimes not, and sometimes feedback would be terminated in the midst of a sucking burst. Consequently, second session performances of these two infants, which were much like their initial performances, were uninterpretable.
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