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Newborn Infants Prefer the Maternal Low-Pass Filtered Voice, But Not the Maternal Whispered Voice

MELANIE J. SPENCE AND MARK S. FREEMAN
The University of Texas at Dallas

This research examined the hypothesis that prenatally available acoustic properties of the maternal voice support newborns' recognition of the maternal voice. We addressed this question first by assessing infants' preference for maternal voice samples that preserved the lower vocal frequencies which are salient in the uterine environment and second by assessing newborns' preference for maternal whispered voice samples that are produced without voicing and do not contain low frequencies. Infants preferred their mothers' voices over unfamiliar female voices when presented 500-Hz low-pass filtered voice samples in a nonnutritive sucking operant choice procedure. Infants did not prefer their mothers' whispered voices, suggesting that they did not recognize them. Three additional experiments further clarified this interpretation. These experiments demonstrated that infants hear whispered voices and that they discriminate unfamiliar whispered voices. Additionally, whispered voices were not reinforcing for newborns, suggesting that acoustic properties that contribute to the reinforcing value of female voices are not present in whispering. These results indicate that vocal properties that are available prenatally are sufficient to support newborns' preference for the maternal voice, and they suggest that fundamental frequency is important for neonatal voice recognition.

newborns auditory preferences maternal voice recognition prenatal experience nonnutritive sucking

Newborn infants prefer their mother's voice over the voice of another female (DeCasper & Fifer, 1980); this effect has been interpreted as reflecting newborns' recognition of the maternal voice (DeCasper & Spence, 1991). Little is known, however, about the acoustic characteristics that support human newborns' voice recognition. Because most of newborns' maternal voice experience has occurred during the prenatal period, maternal voice cues that are available and predominant in the intrauterine environment should be more useful for maternal voice recognition when compared with voice cues that are not consistently available in utero. This series of experiments was designed to examine this hypothesis.

Newborns' recognition of the maternal voice is analogous to demonstrations that certain avian species recognize species-specific calls (Gottlieb, 1981) and the vocal signatures of individuals (Evans, 1980). Experience with very specific types of auditory stimulation accounts for some of these preferences. For example, wood ducklings' approach response to the maternal assembly call is dependent on prenatal exposure to their own embryonic vocalizations (Gottlieb, 1981). Gottlieb (1981) has also identified the acoustic properties that are critical for Peking and wood ducklings' recognition of the species-specific call; this research suggests that there is a hierarchy of importance of acoustic cues that are critical for species-specific recognition. For example, both repetition rate and high frequencies of the maternal call are critical for Peking ducklings' recognition, but repetition rate is more important.

Support for the assertion that human newborns' maternal voice preference is influenced by prenatal experience is provided by evidence that they prefer a speech passage and a melody that their mothers had recited repeatedly only

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Correspondence and requests for reprints should be sent to Melanie J. Spence, School of Human Development, Box 830688, GR 4.1, University of Texas at Dallas, Richardson, TX, 75083–0688, or e-mail: mspence@utdallas.edu.

during the later weeks of pregnancy (DeCasper & Spence, 1986; Panneton, 1985), and that 37-week-old fetuses differentially respond to a nursery rhyme that their mothers recited daily during the prior 4 weeks (DeCasper, Lecanuet, Busnel, Granier-Deferre, & Maugeais, 1994). Additionally, voice stimuli to which infants are less likely to be exposed prenatally, such as fathers' voices, are not recognized by newborns (DeCasper & Prescott, 1984).

Information about acoustic characteristics of the intrauterine environment, including the characteristics of the maternal voice that are transduced into the uterus, has been provided by descriptions and analysis of the spectral properties of audio recordings made from within the uterine environment. Intrauterine recordings conducted with both human and nonhuman subjects have shown that low-frequency auditory stimulation is predominantly available; these low-frequency sounds consist of maternal and placental vascular sounds with intermittent digestive sounds (Gerhardt, Abrams, & Oliver, 1990; Querleu, Renard, & Crepin, 1981; Vince, Armitage, Baldwin, Toner, & Moore, 1982). The low-frequency sounds are all below 1000 Hz, and the overall intensity of the background internal noise is 28 dB.

Extrauterine sounds are also detectable in the uterus; however, the body tissue acts like a low-pass filter (Gerhardt et al., 1990; Querleu et al., 1981; Vince, Armitage, Walser, & Reader, 1982). Higher frequencies are attenuated to a greater extent than lower frequency sounds; as frequencies increase from 125 Hz to 2 kHz, attenuation increases so that, for example, a 250-Hz tone is attenuated 2 dB, and a tone of 1000 Hz is attenuated 20 dB (Querleu et al., 1981). The maternal voice has been detected in utero above the background noise at 52 dB, whereas the intensity of the voices produced by other persons has been measured at about 40 dB (Querleu, Renard, Versyp, Paris-Delrue, & Crepin, 1988). Maternal voice frequencies above 2 kHz are attenuated by 20 dB on average (Querleu et al., 1988), whereas frequencies below 250 Hz are actually enhanced about 5 dB (Richards, Frentzen, Gerhardt, McCann, & Abrams, 1992). Richards et al. (1992) reported that the maternal voice was measured at 77 dB, actually being amplified about 5 dB above the measurement in air (72 dB), and that one-third-octave bands with center frequencies below 250 Hz were enhanced up to 5 dB. Turkewitz (1988) has also argued that extrauterine sounds such as voices may be more efficiently transmitted to the uterus during later gestation; with increasing gestational age, the uterine wall stretches and thins, resulting in the amplification rather than attenuation of externally generated sounds.

Adults' subjective descriptions of these intrauterine voice recordings are that the voices are muffled; attenuation of the high frequencies of voices renders much of speech unintelligible. Adults have identified 30% of French phonemes produced by female speakers from human intrauterine recordings (Versyp, as cited in Querleu et al., 1988) and 33.5% of English consonant-vowel-consonant (CVC) and vowel-consonant-vowel (VCV) utterances recorded from within the sheep uterus (Griffiths, Brown, Gerhardt, Abrams, & Morris, 1994). However, the lowest voice frequencies are available so that the prosodic properties of speech, including frequency contours and temporal and rhythmic properties of speech, are detectable by adults from the intrauterine voice recordings (Querleu et al., 1988).

Converging evidence for the salience of low-frequency signals for the developing fetus is found by examining functional development of the auditory system. During development, low or middle frequencies first elicit both behavioral and physiological responsiveness, with responsiveness to the highest frequencies developing last (Rubel, 1978). The place code along the cochlea also shifts during development so that the basal regions of the cochlea are most sensitive to low frequencies during the initial stages of auditory functioning, and apical regions become more responsive to low frequencies with maturation. Rubel (1985) has suggested that this sequence of auditory development may reflect selection of a developmental pattern that takes advantage of the available environmental stimulation.

The research reported here was conducted in order to identify vocal cues that support newborns' recognition of the maternal voice. The data generated by the intrauterine recording research place us in a strong position to examine the extent to which these vocal properties are the same as those vocal properties that are available in the prenatal auditory environment rather than vocal cues that are primarily experienced postnatally. The first experiment examined if newborns would differentially access the maternal voice when presented a sample of her voice that preserved those acoustic cues most consistently available in utero. A second study examined newborns' responsiveness to a sample of the maternal voice that did not contain many of the prenatally available acoustic cues. If the relevance of acoustic cues is affected by prenatal experience with those cues, then maternal voice samples consisting of the lowest voice frequencies and the prosodic properties conveyed by this spectral range should contain sufficient information for infants' discrimination and preferential responding for the maternal voice. However, voice samples that lack the low-frequency information and associated prosodic properties available in utero may not support newborns' maternal voice preferences.

EXPERIMENT 1

Preference for Maternal Versus Nonmaternal Low-Pass Filtered Voices

The first experiment assessed whether the information conveyed by the lowest frequencies of the maternal voice supports newborns' maternal voice recognition performance. Low frequencies provide sufficient cues for adult listeners' recognition of voices (Abberton & Fourcin, 1978; LaRiviere, 1975); adults recognize voices when presented speech that has been low-pass filtered at 200 Hz so that only fundamental frequency (F_0) is available. Low-frequency information may also support newborns' maternal voice recognition performance. Newborns detect the equivalence across 1000-Hz low-pass filtered and unfiltered versions of their mothers' voices (Spence & DeCasper, 1987). However, this filtering manipulation did not adequately simulate prenatally available vocal properties because the speech produced in these samples was clearly discerned by adult listeners, whereas much of intrauterine-recorded speech is unintelligible (Versyp, as cited in Querleu et al., 1988; Griffiths et al., 1994).

There is some preliminary indication that newborns discriminate maternal and nonmaternal low-pass filtered voices (Moon & Fifer, 1990), but these data are ambiguous because a consistent pattern of responding was not found across the entire sample. A trend toward more frequent activation of 500-Hz low-passed maternal voices over nonmaternal voices was found for the youngest infants (*M* age = 35 hours) but not for the oldest infants (*M* age = 48 hours) in the sample. Additionally, the older infants, but not the younger ones, tended to maintain the maternal voice reinforcer for longer periods once it was activated. The results of these studies that have examined newborns' responsiveness to low-pass filtered voices do not provide definitive evidence that the acoustic properties of voices that are available prenatally are sufficient to support newborns' maternal voice preference.

This experiment examined newborns' preference for the low-pass filtered maternal voice or the low-pass filtered voice of another female using an operant choice procedure (DeCasper & Fifer, 1980; DeCasper & Spence, 1986). Infants were presented tape recordings of female voices that were low-pass filtered at 500 Hz with a steep attenuation slope, –96 dB/octave, which effectively attenuated all frequencies above 750 Hz below auditory thresholds.

Low-pass filtering of speech removes the linguistic content, because cues for phonemic distinctions are conveyed primarily by high frequencies, whereas it preserves the prosodic characteristics of speech, such as the frequency contours, amplitude variations, temporal patterning of the language and of the speaker, and the phrase structure of the language. The overall quality and timbre of voices are also mostly conveyed by the lower frequencies of the voice. Average fundamental frequencies of vowels produced by female voices, which range from 210 Hz to 235 Hz (Peterson & Barney, 1952) and are important cues for adults' identification of speakers (Abberton & Fourcin, 1978; LaRiviere, 1975), also are well within this range. It is likely that some combination of attributes, such as F_0, frequency contour, and temporal patterning, provides the necessary cues for voice recognition. One-month-old infants, for example, discriminate the maternal voice from another female voice when intonated voices are presented, but they do not discriminate monotone versions which disrupt the natural temporal properties of speech (Mehler, Bertoncini, Barriere, & Jassik-Gerschenfeld, 1978).

It was predicted that newborns would respond more frequently to access the maternal voice relative to the nonmaternal voice because vocal frequencies under 500 Hz convey the prosodic properties and F0 of female speech and because these vocal characteristics have been frequently experienced by newborns. These results would suggest that the cues conveyed by the low-passed manipulation are sufficient for maternal voice recognition.

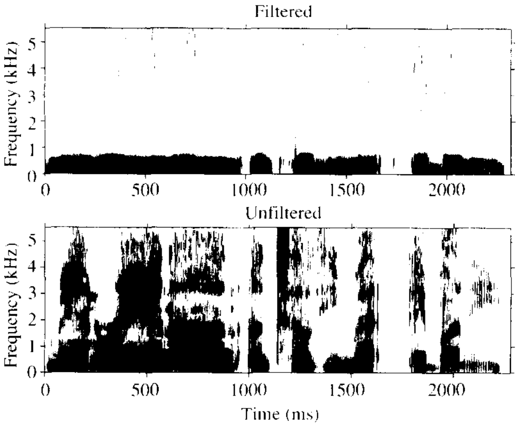

Figure 1. Spectrograms of a female producing the utterance "ran on until he met a bunny" and the same utterance low-pass filtered at 500 Hz with −96 dB/octave attenuation.

Method

Subjects

Sixteen full-term newborn infants (8 males, 8 females), with a mean age of 31 hours (range = 19–73 hours), completed the experiment. Each infant who met criterion for inclusion in the study had an uncomplicated gestation and delivery, Apgar scores of 8 or above at 1 and 5 min after birth, and birthweight between 2,800 and 4,000 gms. Male infants were tested either before or at least 12 hours after circumcisions were performed.

Testing was attempted with 62 infants in order to obtain completed sessions from 16. Sixteen infants could not be brought to a quiet alert state at the time of testing, 8 infants failed to produce sucking bursts exceeding the minimum intensity during the sucking adjustment period, and 7 produced baseline median interburst intervals (IBIs) outside the range of typical IBIs (less than 2 s or greater than 8 s) and were not tested in the operant condition. Twelve sessions were not completed due to infants crying (n = 2) or falling asleep (n = 10), and session interruptions or equipment problems occurred during 3 sessions.

Stimuli

Low-pass filtered recordings of female voices reading "The Gingerbread Man" were the auditory stimuli presented as reinforcing stimuli. Each mother who consented to participate in the study was given a typed transcript of the story and asked to read the story as if reading to her infant. Recording was conducted in a quiet room using a Marantz PMD 201 cassette recorder and an EC-5 Cardioid microphone.

Each woman's recording was then low-pass filtered through two Norcom Butterworth filters placed in series, and the output from the second filter was tape-recorded. Voices were low-pass filtered with attenuation of −96 dB/octave above the nominal cutoff frequency of 500 Hz. Spectrograms of both filtered and unfiltered versions of an utterance produced by one speaker are presented in Figure 1. The low-pass filtered recordings were presented at intensities averaging between 68 dB and 72 dB SPL (A-weighting) measured at the earphones using a Radio Shack sound level meter. The intensities of each pair of voices presented were also adjusted to equate for perceived loudness by two adult listeners.

Each infant was presented the filtered recording of his/her own mother and the filtered recording made by another infant's mother. Thus, the nonmaternal voice presented to each infant was the voice of another infant's mother which was recorded and low-pass filtered under similar conditions.

Apparatus

Sessions were conducted in a quiet, dimly lit room in the hospital nursery area. Infants were placed supine in their bassinets, fitted with TDH-49 earphones which were suspended from a flexible rod, and given a newborn-sized pacifier. The pacifier was connected with tygon tubing to an Omega PX161-027 pressure transducer, which detected positive sucking pressure exerted on the nipple. The transducer signal was input to a computer which recorded infant sucking and controlled the experimental procedure and presentation of the auditory reinforcers. The two tape recordings which each infant heard were playing continuously on separate Marantz PMD 201 cassette recorders. The output of each of the recorders was gated to the infant's earphones through a capacitively coupled circuit so that clicks were eliminated. Auditory output was presented over the headphones contingent on the nonnutritive sucking pattern.

Procedure

Informed consent was obtained from mothers of infants who met criteria for inclusion in the study; their voices were then tape-recorded and low-pass filtered. Each infant was tested after being brought to a quiet alert state. Each infant was required to fixate and follow an experimenter's face when she spoke to the infant before testing began. Each infant was then placed supine in a bassinet, fitted with earphones, and one experimenter held the pacifier in the infant's mouth. This experimenter was blind to the experimental condition of the infant and stood out of the infant's visual field. The second experimenter monitored the equipment and infant behavior. Each infant was given approximately 2 min to adjust to the situation and to emit sucks with positive pressures exceeding 20 mm Hg.

Baseline sucking patterns were first recorded until 12 sucking bursts and interburst intervals were obtained. No voices were presented over the earphones during acquisition of the baseline sucking pattern. A sucking burst was defined as a series of sucks, with each suck separated by less than 2 s. The computer program registered the end of the burst when 2 s elapsed without a suck. The lengths of IBIs were timed beginning 2 s after the last suck of one burst and ending with the onset of the first suck of the next burst (DeCasper & Spence, 1986). The median value of IBIs produced by each infant was computed, and the median IBI length was used in the experimental session as the criterion for differentially reinforcing sucking bursts.

Infants who produced median IBIs within the typical distribution of IBIs (2–8 s) were then presented the operant procedure (see DeCasper & Spence, 1986, for discussion of this issue).

The operant phase, which consisted of differential reinforcement of IBIs, began immediately after computation of the baseline median IBI. Testing continued until a minimum of 8 min of sucking was obtained. If infants stopped sucking for a 1-min period for any reason, or if they fell asleep, the session was terminated, and the infant was returned to the nursery. Sixteen infants remained quietly alert for the minimum session length.

Reinforcement Contingencies. During the operant phase, sucking that exceeded the threshold of 20 mm Hg intensity was reinforced with the output from either of the two tape recorders. Each infant could access only one voice at a time; either the maternal or a nonmaternal low-pass filtered voice was presented contingent on the onset of sucking and remained on until 2 s elapsed without a suck. For 8 randomly selected infants (4 males, 4 females), sucking that ended IBIs less than that infant's baseline median IBI value was reinforced with the recording of the maternal low-pass filtered voice, whereas sucking that ended IBIs greater than or equal to that infant's baseline median IBI was reinforced with the non-maternal low-passed voice. For this group of infants, the maternal voice was accessed by producing IBIs which were shorter than the median IBI value. The other 8 infants (4 males, 4 females) were presented the reverse contingencies; sucking ending IBIs less than that infant's baseline median IBI was reinforced with the nonmaternal low-passed voice, whereas sucking ending IBIs greater than or equal to the baseline median IBI was reinforced with the maternal low-passed voice. Reinforcement contingencies were counterbalanced to control for changes in sucking behavior which might occur due to arousal or fatigue as well as for any possible response biases that might occur from either of the contingencies.

Results and Discussion

The numbers of IBIs terminated by sucking bursts that were reinforced with the maternal and nonmaternal voices served as the primary dependent measure in an ANOVA in which experimental condition (greater than median IBI or less than median IBI) was the between-subjects factor, and voice (maternal vs. nonmaternal) served as a repeated factor. A main effect of voice resulted, $F(1, 14) = 5.97$, $p < .03$, such that infants produced more IBIs that were reinforced with the maternal low-pass filtered voice ($M = 30.25$, $SD = 13.81$) than with the nonmaternal low-passed voice ($M = 22.19$, $SD = 10.46$).

A second dependent measure, the relative frequency of IBIs reinforced with the maternal voice, was computed in order to examine whether the frequency of responding reinforced with the maternal voice differed from baseline. The relative frequency was computed by dividing the number of IBIs reinforced with the maternal voice by the total number of IBIs produced by that infant during the experimental session. The relative frequencies were entered into a one-tailed t test in which the mean relative frequency value was compared with 50%, the value that would be expected if sucking patterns did not change from baseline. A one-tailed t test was used because it was specifically predicted that responding for the maternal voice should be greater than 50%. Comparison of the relative frequency values of the 16 participants with 50% revealed that infants produced significantly more IBIs that were reinforced with the maternal voice than expected based on their baseline performance, one-tailed $t(15) = 2.65$, $p < .05$. The average relative frequency values for each counterbalanced condition are shown in Figure 2. For infants in the less-than-median condition, 58% of their IBIs were shorter than the median ($SE = .04$), whereas 56% of IBIs ($SE = .03$) produced by infants in the greater-than-median condition were reinforced with the maternal voice. Examination of the individual participant data revealed that 6 of 8 infants in each condition altered their distribution of IBIs in the direction required to access the mother's voice.

These results indicate that infants responded more frequently in a nonnutritive sucking task to activate their mothers' 500-Hz low-pass filtered voices, revealing that the acoustic cues conveyed by the lower frequencies provide sufficient information for newborns' voice recog-

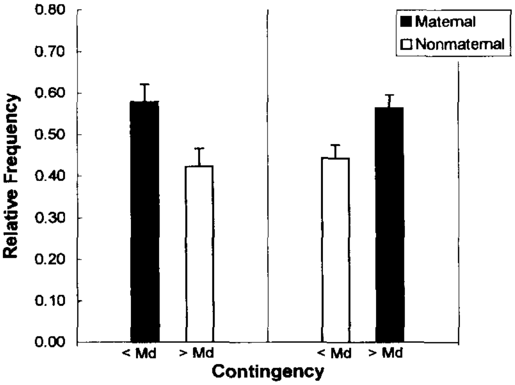

Figure 2. Mean relative frequencies (and standard errors) of sucking reinforced with the maternal and nonmaternal low-pass filtered voices as a function of contingency condition.

nition. The filtering manipulation preserved those acoustic cues that are most consistently available in utero and that have been most frequently experienced by newborns. The relative salience of each of these cues for voice recognition, which include F_0, F_0 contour, amplitude variation, and speaking tempo, cannot be determined from these data. However, it can be stated that some subset of these cues provides sufficient support for newborns' recognition of the maternal voice.

EXPERIMENT 2

Preference for Maternal Versus Nonmaternal Whispered Voices

The second experiment examined newborns' preference for the maternal voice using a voice stimulus that did not have the same acoustic properties as the intrauterine-recorded maternal voice. Intrauterine recordings have shown that vocal frequencies above 1000 Hz are attenuated more severely than lower ones, and that frequency contour, and temporal and rhythmic properties of speech are available in intrauterine recordings (Gerhardt et al., 1990; Querleu et al., 1981; Querleu et al., 1988; Vince et al., 1982). Several acoustic properties that seem likely to support voice recognition by newborns are F_0, frequency contour, and speaker-specific temporal and rhythmic characteristics. A voice stimulus that does not share properties with the intrauterine voice stimulus would consist of higher vocal frequencies but would not contain the lowest frequencies, including the F_0, or other prosodic cues that are predominant prenatally.

Choice of Test Stimulus

Two different types of voice stimuli, high-pass filtered speech and whispered speech, meet these criteria and were considered for this study. High-passed speech was considered less appropriate for testing the hypothesis than whispered speech given a comparison of their acoustic characteristics. The lower frequencies of voices are missing from both high-passed and whispered speech. Whispered speech is produced by resonance through the vocal tract without periodic pulsing of the larynx and consequently does not have the speaker's F_0, the harmonics, or the frequency contours of normally phonated speech. High-passing of speech attenuates those frequencies below the cutoff frequency; high-passing at 500 Hz would effectively remove F_0 from the signal. High-passing does, however, retain the higher harmonics of the F_0 which can evoke a sensation of pitch (Ritsma, 1967). Thus, even though the F_0 itself would be removed from the signal, cues for perception of F_0 would be available. The best evidence for the importance of lower vocal frequencies for voice recognition would be provided by using stimuli from which the low frequencies have been removed as well as all cues for perception of the low frequencies. Whispered speech has no voicing component and so does not contain F_0 or harmonics that may support perception of the F_0.

A second difference between the two types of speech exists in preservation of the higher frequencies of speech, specifically, the formant frequency structure. Formant structure, which results from resonance through the vocal cavities, contributes significantly to speaker recognition by adults (Abberton & Fourcin, 1978; LaRiviere, 1975; Pollack, Pickett, & Sumby, 1954), and its importance for adults' voice recognition has typically been assessed using whispered voices (Abberton & Fourcin, 1978; LaRiviere, 1975). Whispered speech preserves formant frequency structure, although the formants are slightly higher than normally phonated formants (Kallail & Emanuel, 1984) and the first formant (F_1) is attenuated (Peterson, 1961), as can be seen in Figure 3. Formant structure of 500 HZ high-passed speech is disrupted because F_1 is effectively removed.

Whispered speech, which lacks cues for perception of F_0 but preserves formant frequency structure, was judged to be a more appropriate stimulus than high-passed speech for testing the hypothesis that low-frequency information is crucial for supporting newborns' maternal voice recognition. Whispering also preserves prosodic characteristics, such as phrase structure, rhythm, and tempo, as well as cues that are important for phonemic discriminations such as frequency transitions, transition durations, and burst and frication spectra (Tartter, 1989, 1991). Finally, because the independent contributions of formant structure and F_0 information have been demonstrated in the adult voice recognition literature using whispered and low-passed voice stimuli (Abberton & Fourcin, 1978; LaRiviere, 1975; Pollack et al., 1954), a similar comparison between whispered and low-passed voices seemed appropriate for our research.

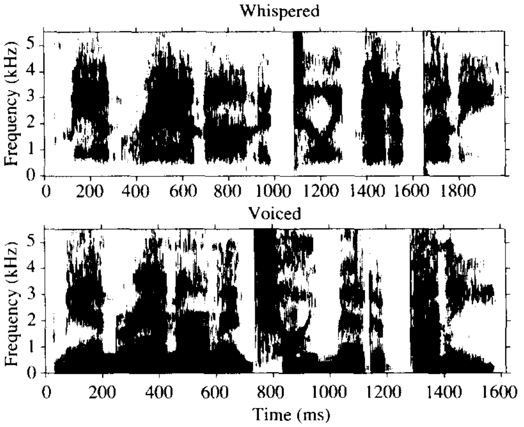

Figure 3. Spectrograms of a female producing both voiced and whispered renditions of the utterance "ran on until he met a bunny."

Purpose of This Study

In the second experiment, whispered maternal and nonmaternal voices were presented to infants. The maternal voice has been shown to be more reinforcing for newborns than other female voices in spite of variations in spectral composition, for example, unfiltered and 500-Hz low-pass filtered (DeCasper & Fifer, 1980; Experiment 1, respectively), or differences in prosodic properties inherent in infant-directed speech versus adult-directed speech (DeCasper & Fifer, 1980; Fifer & Moon, 1989). Newborns would also be expected to prefer the maternal whispered voice if the acoustic cues that support voice recognition are present in the whispered voice and/or if properties that are invariant across phonated and whispered speech are detected by infants. However, if newborns do not detect the invariant properties across phonated and whispered speech as do adults, or the maternal voice preference is dependent on properties that are missing from whispered speech, then infants should not prefer the maternal whispered voice.

Method

Subjects and Stimuli

Eighteen full-term newborn infants (8 males, 10 females), with a mean age of 28 hours (range = 14–63 hours), completed the experimental session. Each infant met the same criteria as infants in Experiment 1. Seventy-one infants were tested in order to obtain these data. Ten infants could not be brought to a quiet alert state, 8 infants failed to produce baseline sucking which exceeded the minimum intensity, and 8 produced extreme baseline median IBIs. Five sessions were aborted due to session interruptions or equipment problems, and 16 infants were lost for sleeping and 6 sessions were terminated due to infant crying.

Whispered recordings of female voices reading "The Gingerbread Man" were the auditory stimuli presented as reinforcers. Each mother who consented to participate in the study was given a typed transcript of the story and instructed to whisper without voicing and with appropriate intonation. The whispered voice recordings were presented at intensities averaging between 68 dB and 75 dB SPL (A-weighting) measured at the earphones using a Radio Shack sound level meter. The intensities of each pair of voices presented were also equated for perceived loudness by two adult listeners. Spectrograms of a whispered utterance as well as the normally phonated utterance produced by the same speaker are shown in Figure 3. Each infant was presented the whispered recording of his/her own mother and the whispered recording made by another infant's mother.

Apparatus and Procedure

The apparatus, procedure, and reinforcement contingencies were identical to those described in Experiment 1 with the exception that each infant could access either the recording of the whispered maternal voice or the recording of another whispering female by producing IBIs which were greater than or less than their baseline median IBI. For infants in the less-than condition (4 males, 5 females), sucking bursts ending IBIs less than the baseline median IBI were reinforced with the whispered maternal voice, whereas IBIs greater than or equal to the baseline IBI median were reinforced with the whispered nonmaternal voice. Infants in the greater-than condition (4 males, 5 females) received the reverse contingencies.

Results and Discussion

The number of IBIs terminated by sucking bursts that were reinforced with the maternal and nonmaternal whispered voices served as the primary dependent measure in an ANOVA in which experimental condition (greater than median IBI or less than median IBI) was the between-subjects factor, and voice (maternal vs. nonmaternal) served as a repeated factor. There was no main effect of voice, but a significant interaction of voice and condition was found, $F(1, 16) = 5.83, p < .03$. This interaction resulted from a difference between the frequencies of responding to hear the nonmaternal whispered voice across conditions (less-than condition: $M = 32.33$, $SD = 8.86$; greater-than condition: $M = 19.11$, $SD = 8.92$), whereas no difference in responding to hear the maternal whispered voice occurred across conditions (less-than condition: $M = 27.78$, $SD = 11.66$; greater than condition: $M = 28.89$, $SD = 8.07$).

Relative frequencies of IBIs reinforced with the whispered maternal voice and the whispered nonmaternal voice were computed for each infant and entered into a one-tailed t test comparing the mean relative frequency value with 50%, the expected frequency of IBIs based on baseline production. A directional test was conducted because the hypothesis being tested was that responding for the maternal whispered voice would increase over baseline values. Infants did not produce the maternal whispered voice more than expected based on baseline performance, $t(17) = 1.04$. As shown in Figure 4, infants in the less-than-median condition responded to hear the maternal voice during an average of 45% of the trials ($SE = .04$), with only 4 of 9 infants producing relative frequency values greater than 50%. Infants in the greater-than-median condition responded to hear the maternal voice an average of 61% ($SE = .04$) of the experimental trials, with 7 of 9 infants producing more IBIs larger than the baseline median value.

Newborns did not consistently exhibit preferential responding for the whispered maternal voice; this result is consistent with the hypothesis that acoustic cues that support newborns' voice recognition are not available in whispered voices. However, the absence of a preference could also occur either if infants are unable to discriminate two whispered voices or if they can discriminate the voices but they are not differentially reinforcing.

A third explanation for this effect is that infants could not detect the whispered stimuli. This explanation would also explain the response bias toward long IBIs found in Experiment 2 and which is shown in Figure 4; infants in both counterbalanced groups increased the lengths of their IBIs above baseline. Infants might consistently produce longer pauses between sucking bursts if no consequence for sucking is detected. Although the whispered voices were presented via earphones at intensities at which normal speech is detected, failure to detect the stimuli cannot be ruled out with these data.

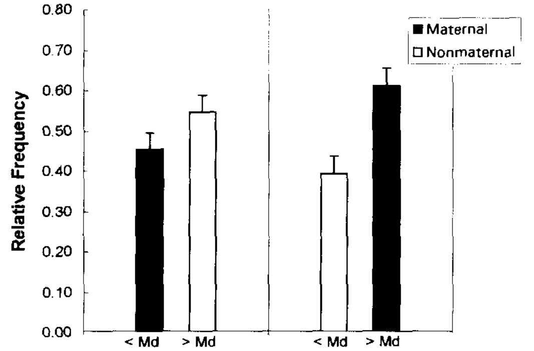

Figure 4. Mean relative frequencies (and standard errors) of sucking as a function of contingency condition when maternal and nonmaternal whispered voices served as consequences of sucking.

EXPERIMENT 3

Detection of Whispered Voices

A third experiment was conducted to determine if infants could detect whispered voices. Infants' sucking was measured during a 4-min baseline during which there were no consequences for sucking. A whispered voice was then presented contingent on sucking during the following 2 min. If infants can detect the whispered voice, then sucking rates should increase in the final 2-min period over sucking rates during which no auditory consequences are available. The performance of infants in this experimental manipulation was compared with sucking rates of a control group for which sucking received no consequences for the entire 6-min session.

Method

Subjects and Stimuli

Twelve newborns (M age = 26.5 hours, range = 15–42 hours; 8 females, 4 males), meeting the same criteria outlined in the previous experiments, completed the experimental session. Six were randomly assigned to the experimental condition, and 6 were assigned to the control condition. Testing of an additional 16 infants was attempted but was unsuccessful due to infants falling asleep or crying ($n = 6$), not sucking ($n = 4$), and session interruptions and equipment problems ($n = 4$). Two infants would not awaken or accept the pacifier in order to begin the session.

Recordings of female whispered voices from Experiment 2 were presented as stimuli; each experimental infant in Experiment 3 was presented a different whispered voice. The whispered voice recordings were presented at intensities averaging between 68 and 75 dB SPL (A-weighting) measured at the earphones using a Radio Shack sound level meter.

Apparatus and Procedure

Infants were placed supine in their bassinets, fitted with earphones, and given a nonnutritive nipple. Sucking was recorded using a Lafayette Datagraph one-channel recorder. For the experimental group, sucking during the first 4 min of the session resulted in no consequences; no auditory stimuli were presented over the earphones. Beginning with the 5th min, a whispered female voice was presented over the earphones contingent on sucking. Each suck produced a 2-s presentation of the whispered voice so that sucks separated by less than 2 s resulted in continuous presentation of the voice. The voice remained on until 2 s had elapsed during which no sucks occurred. Presentation of the whispered voice as a consequence of sucking continued for 2 min. Infants in the control group were also fitted with earphones, but no auditory stimuli were presented over the earphones for the entire 6-min session.

Results and Discussion

The mean number of sucks exceeding a 20-mm Hg threshold produced by each infant during each 2-min block was computed. The mean number of sucks for each infant in the last 2 min of baseline (Min 3 and 4) and the 2 min during which whispered voices were presented as consequences of sucking (Min 5 and 6) served as the dependent measure. These means were entered into an ANOVA in which condition (experimental or control) was the between-subjects factor, and period (baseline vs. test) was the repeated factor. A significant interaction resulted, $F(1, 10) = 5.08$, $p < .05$, as illustrated in Figure 5. Five of 6 experimental infants increased sucking from the second baseline period (Min 3 and 4: $M = 40.67$, $SE = 6.64$) to the test period (Min 5 and 6: $M = 48.83$, $SE = 5.08$), whereas 5 of 6 control infants decreased sucking across these periods (Min 3 and 4: $M = 41.50$, $SE = 4.36$; Min 5 and 6: $M = 37.50$, $SE = 4.62$).

These results indicate that infants detected the whispered female voices presented over earphones at 68 dB to 75 dB; when sucking resulted in no auditory contingencies and was then followed by the presentation of a whispered voice for 2 min, infants' sucking rates increased relative to the rate of a control group, suggesting an arousal response to the whispered stimuli. These results also suggest that the absence of a maternal voice preference in Experiment 2 did not result from infants' failure to detect the whispered stimuli. Rather, the absence of a maternal voice preference occurred either because newborns could not discriminate two whispered voices or because maternal whispered voices were not differentially reinforcing. The following two experiments were conducted to test these possibilities.

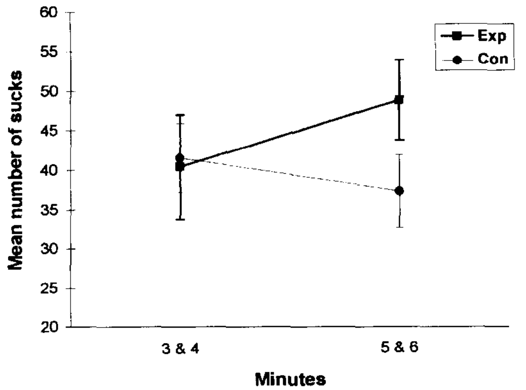

Figure 5. Mean sucking rate (and standard errors) of experimental (Exp) and control (Con) groups during baseline and test conditions.

EXPERIMENT 4

Discrimination of Whispered Voices

Whispered speech has not been frequently experienced by newborns and it lacks low-frequency properties that are salient for young infants. Because most of newborns' previous voice experience has been with low-frequency voiced information, they may not attend the acoustic properties of whispered voices which differentiate them. Experiment 4 used a high-amplitude sucking procedure to assess whether newborns discriminate two whispered voices. Newborns in the experimental group were presented a whispered voice contingent on sucking until sucking rate habituated and then were presented a novel whispered voice. Recovery of sucking upon presentation of a novel voice would be expected if they discriminate the whispered voices.

Method

Subjects and Stimuli

Twelve newborns (M age = 36.4 hours, range = 17–53 hours; 6 females, 6 males), meeting the same criteria outlined in the previous experiments, completed the procedure. Six were randomly assigned to the experimental condition, and 6 were assigned to the control condition. Testing of an additional 9 infants was attempted but was unsuccessful; 3 infants would not awaken in order to begin the session, 4 infants fell asleep or cried, and 2 would not produce sucking.

Recordings of pairs of female whispered voices from Experiment 2 were presented as stimuli; each experimental infant in Experiment 4 was presented a different pair of whispered voices. The whispered voice recordings were presented at intensities averaging between 68 and 75 dB SPL (A-weighting) measured at the earphones using a Radio Shack sound level meter.

Apparatus and Procedure

Infants were placed supine in their bassinets, fitted with earphones, and given a nonnutritive nipple. Sucking was recorded using a Lafayette Datagraph one-channel recorder. A high-amplitude sucking habituation procedure was used to assess discrimination of the stimuli. For infants in both experimental and control groups, sucking that exceeded an intensity of 20 mm Hg was reinforced with a whispered female voice presented over the earphones. Each suck produced a 2-s presentation of the whispered voice so that sucks separated by less than 2 s resulted in continuous presentation of the voice. The voice remained on until 2 s had elapsed during which no sucks occurred.

Presentation of the familiarization stimulus continued until each infant's sucking rate decreased 20% for 2 consecutive min below the rate of the preceding minute (Jusczyk, 1985). When each infant attained this criterion level of sucking, infants in the experimental group were presented a second whispered voice contingent on sucking for 2 min. Infants in the control group continued to hear the same voice that was presented during the habituation phase of the experiment.

Results and Discussion

The mean numbers of sucks produced by each infant in the 2 min meeting the criterion level and the 2 min following the criterion level were computed. These means were entered into an ANOVA in which condition (experimental vs. control) was a between-subjects factor and period (criterion or −2 and −1 vs. postcriterion or 1 and 2) served as a repeated factor. A significant interaction of condition and period was found, $F(1, 10) = 10.55$, $p < .01$. As can be seen in Figure 6, the control and experimental groups did not differ during the criterion period (experimental $M = 28.83$, $SE = 5.30$, control $M = 27.58$, $SE = 5.98$), but the experimental group produced a higher sucking rate than the control group in the postcriterion period (experimental $M = 41.42$, $SE = 5.81$, control $M = 18.83$, $SE = 5.86$). Sucking of 5 of 6 experimental infants increased from criterion to postcriterion periods, whereas sucking of 5 of 6 control infants decreased from criterion to postcriterion periods.

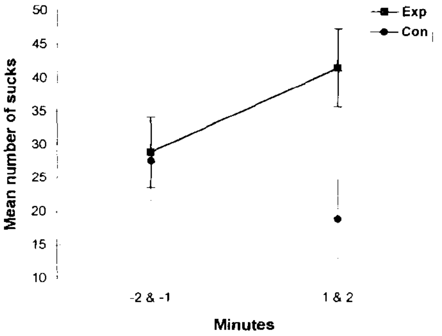

Figure 6. Mean sucking rate (and standard errors) of experimental (Exp) and control (Con) groups during the criterion and postcriterion periods.

These results indicate that newborns discriminate two unfamiliar female whispered voices and imply that newborns should have been capable of discriminating the whispered maternal and nonmaternal voices. This finding also suggests that the results of Experiment 2 most likely occurred because maternal whispered voices were not differentially reinforcing. Maternal whispered voices would not be differentially reinforcing if properties that typically support or contribute to their reinforcing value are missing from the whispered signal. In fact, whispered voices are so discrepant from normally phonated voices that perhaps they are not reinforcing stimuli for newborns and would fail to maintain responding during an extended experimental session after the arousal effect has abated. Support for this notion would provide converging evidence for the results of Experiment 2; if whispered voices do not contain the properties that contribute to the reinforcing value of voices, then those same properties would also be missing from samples of the maternal whispered voice.

EXPERIMENT 5

Preference for Whispered Voices Versus Silence

The fifth experiment was conducted to examine if whispered female voices serve as reinforcing stimuli for newborn infants. Female speech and female singing (Butterfield & Siperstein, 1972; DeCasper & Carstens, 1981; DeCasper & Sigafoos, 1983) are reinforcing stimuli for newborns. Female whispered voices should also be reinforcing if they contain properties that contribute to the reinforcing value of the class of female voices. Previous research has revealed that newborns will suck in order to avoid white noise, which has an aperiodic source (Butterfield & Siperstein, 1972). Whispering, with its aperiodic or noisy source, may also be aversive, or it may provide no reinforcing value for infants. In order to examine the reinforcing value of whispered speech for newborns, infants were presented either no auditory consequence (silence) or a recording of female whispering contingent on sucking bursts produced in an operant choice task.

Method

Subjects and Stimuli

Sixteen full-term newborn infants (8 males, 8 females), with a mean age of 25 hours (range = 14–35 hours), completed the experimental procedure. Testing of an additional

30 infants was attempted, but these infants would not maintain a quiet alert state or refused the pacifier. Experimental sessions were begun with 36 infants. Out of this group, 12 failed to remain quietly alert, 4 failed to produce sucking of adequate intensity, 3 produced extreme baseline median IBIs, and 1 infant was lost due to equipment problems.

Whispered recordings of female voices reading "The Gingerbread Man" from Experiment 2 were the auditory stimuli. The whispered voice recordings were presented at intensities averaging between 68 and 75 dB SPL (A-weighting) measured at the earphones using a Radio Shack sound level meter.

Apparatus and Procedure

The apparatus, procedure, and reinforcement contingencies were identical to those described in Experiments 1 and 2, with the exception that each infant could access either the whispered female voice recording or silence by producing IBIs that were greater than or less than their baseline median IBI. For infants in the less-than condition (4 males, 4 females), sucking bursts ending IBIs less than the baseline median IBI were reinforced with the whispered female voice, whereas IBIs greater than or equal to the baseline IBI median were reinforced with silence. Infants in the greater-than condition (4 males, 4 females) received the reverse contingencies.

Results and Discussion

The number of IBIs terminated by sucking bursts that were reinforced with whispered voices or silence served as the primary dependent measure in an ANOVA in which experimental condition (greater than median IBI or less than median IBI) was the between-subjects factor, and consequence (whispered voice vs. silence) served as a repeated factor. No significant effects were found.

Relative frequencies of IBIs which were reinforced with the whispered female voice were computed for each infant and entered into a one-tailed t test comparing the mean relative frequency with 50%, the expected frequency of IBIs based on baseline production. A directional test was conducted to test whether responding increased above baseline values. Infants did not activate the whispered voice more than expected based on baseline performance, $t(15) = 0.69$. Infants in the less-than-median condition responded to hear the whispered voice during an average of 48% of the sucking bursts produced ($SE = .05$), with 3 of 8 infants producing relative frequency values greater than 50%. Infants in the greater-than-median condition responded to hear the whispered voice an average of 57% ($SE = .07$) of the experimental trials, with 4 of 8 infants producing more IBIs larger than the baseline median value.

Whispered speech was no more reinforcing than silence for newborn infants. These results suggest that acoustic properties that contribute to the reinforcing value of voices for newborns are not present in whispered speech. A consistent trend toward producing longer IBIs, like that found in Experiment 2, was also apparent in this study. The response bias toward production of longer IBIs seems to have resulted as an artifact of the stimuli presented as consequences of responding. Because whispered voices do not function as reinforcing stimuli for newborns, in both Experiments 2 and 4, baseline sucking rates were not maintained over the session, and overall sucking rate decreased.

GENERAL DISCUSSION

Newborns preferred a 500-Hz low-pass filtered sample of the maternal voice over another low-passed female voice, indicating that they recognized the low-pass filtered maternal voice. However, they did not prefer the maternal whispered voice, suggesting that the acoustic cues that support maternal voice recognition are not present in whispered speech. This interpretation is supported by the findings that infants could hear the whispered stimuli (Experiment 3), and that they discriminated two whispered voices (Experiment 4). Additionally, whispered voices were not reinforcing stimuli for newborns (Experiment 5). These results suggest that even though newborns can perceive some structure or patterning of whispered voices, the vocal features that contribute to the reinforcing value of voices and that are also critical for newborns' voice recognition are not available in whispered voices.

The pattern of results revealed by the whisper experiments and this interpretation are analogous to those reported for newborns' responsiveness to male voices. DeCasper and Prescott (1984) reported that newborns did not prefer their fathers' voices, even though the infants in their study were exposed postnatally to their fathers' voices. Support for their conclusion that newborns did not recognize the father's voice was provided by demonstrations that newborns could discriminate two unfamiliar male voices, but that male voices were not reinforcing for them. This data, in conjunction with knowledge that the incidence of prenatal exposure to fathers' voices is likely to be much less than prenatal maternal voice exposure, support the assertion of DeCasper and Prescott that early voice preferences are more strongly influenced by prenatal voice experience than postnatal experience. The acoustic properties of whispered maternal speech are also unlikely to be experienced prenatally, resulting in infants' failure to recognize those acoustic properties of the mother's voice in spite of possible postnatal exposure to whispered speech (Fernald & Simon, 1984).

Newborns' failure to recognize the maternal whispered voice contrasts with adults' accurate speaker recognition performance when presented samples of whispered speech. Speaker recognition rates of 90% have been reported for adults when presented 3.4-s and four-word whispered utterances (Abberton & Fourcin, 1978; LaRiviere, 1975; Pollack et al., 1954). Adults also accurately match whispered and phonated syllables produced by the same unfamiliar speaker without prior training (Tartter, 1991). Newborns' inability to detect the constant vocal properties across whispered and phonated registers is consistent with perceptual learning theory (Gibson, 1969) in that relatively more experience with voices and/or with whispering may be needed in order to detect and process the invariant properties shared by phonated and whispered voices. Newborns did, however, detect some patterning in whispered speech that allowed them to distinguish between two unfamiliar voices. We cannot identify the acoustic properties that newborns detected during the discrimination task; however, our informal listening revealed differences between some pairs of voices in speaking rate as well as perceived pitch. Infants may discriminate voices using these or other acoustic properties, but extensive experience with these properties may be necessary before they are incorporated into infants' representation of the maternal voice.

The pattern of results found in Experiments 1 and 2 is especially interesting when considered in the context of previous research which has demonstrated that wider-band spectrum voice samples are generally more reinforcing for young infants than narrow-band spectrum voice samples. For example, newborns prefer unfiltered nonmaternal voices to 1000-Hz low-pass filtered voices (Spence & DeCasper, 1987), whereas 1-month-olds prefer a natural version of infant-directed (ID) speech over low-pass filtered ID speech (Cooper & Aslin, 1994). The whispered voices did consist of broader spectrums than the low-passed samples, but whispered voices were not reinforcing. These results suggest that the reinforcing value of a voice stimulus is not determined solely by bandwidth, but that F_0 and/or harmonic information contribute to the reinforcing value of a broad-spectrum voice stimulus.

These data allow us to begin to identify properties that support newborns' maternal voice recognition; comparison of infants' responsiveness to low-passed and whispered voices suggests that F_0 is important for newborns' voice recognition. The speaker's F_0 is preserved in 500-Hz low-pass filtering but is not present in whispered speech. Not only is F_0 not present in whispered speech, but adults cannot perceive F_0 from whispered speech; adult listeners perceive the pitch of whispered vowels as matching the frequency of the whispered second formant (Thomas, 1969). The importance of F_0 for young infants' processing of sounds is also supported by the recent finding that 2-month-olds (Clarkson, Martin, Meyers, Miciek, & Godfrey, 1996), unlike 7-month-olds (Clarkson & Clifton, 1985; Clarkson & Rogers, 1995), do not perceive the missing F_0 of harmonic tonal complexes. Two-month-olds' inability to perceive pitch from harmonic structure suggests that the presence of F_0 is necessary for their perception of pitch and implies that F_0 may also be important for newborns' processing of sounds. Previous demonstrations of the role of fundamental frequency contour in determining young infants' preferences for ID over adult-directed speech (Fernald & Kuhl, 1987) also support the hypothesis that F_0 plays an important role in voice recognition.

Although there is converging support for the assertion that F_0 supports newborns' maternal voice preferences, the definition of F_0 as a critical property, as well as the relative importance of F_0 and other acoustic properties, such as temporal patterning, cannot be specified until further manipulations are conducted. Multiple cues operating together but with differing contributions probably support newborns' recognition, as has been found by Gottlieb (1985) in his work examining recognition of species-specific vocalizations by various avian species. It is possible, for example, that both F_0 and temporal information are necessary for supporting newborns' voice recognition, but that F_0 is more important. The results reported here are consistent with this hypothesis, because whispered voices, which retain temporal cues but not Fo, were not recognized, but low-passed voices, which retain both types of information, were recognized. Alternatively, the hierarchical organization of cues that are most useful for newborns' recognition of individual voices may vary across voices. Studies of adults' recognition of familiar voices have demonstrated that certain acoustic cues are relatively more important for identifying some voices than others (Van Lancker, Kreiman, & Emmorey, 1985; Van Lancker, Kreiman, & Wickens, 1985). For example, voice Fo and frequency range are better cues for some voices than speaking rate or temporal properties of speech, whereas speaking rate is the better cue for other voices. Whether young infants are sensitive to such voice-specific cues or whether they attend and encode the same set of cues for all voices remains to be determined.

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