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MUSICAL EXPERIENCES OF THE UNBORN BABY

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1. INTRODUCTION

As the human fetus approaches the time of its delivery, sounds from both within the mother-to-be and sounds from the external environment are readily perceived. Documented evidence for auditory perception derives most convincingly from the general experience of pregnant women who describe fetal movements in response to sounds of certain frequencies and levels. Supporting evidence comes from clinical experiments in which it has been demonstrated that newborn infants less than three days old will change the pattern of their bottle sucking patterns in order to hear recordings of their own mother's voice over other female voices [1].

These perceptual studies together with actual measurements of the sounds present in the uterus of pregnant women and also from pregnant sheep, an excellent animal model for sound transmission studies, leave no doubt about the existence of a varied fetal sound environment. Sounds in the uterus are dominated by mother's voice as well as other internal noises and permeated by rich and diversified rhythmic and tonal surrounding sounds [2–4].

The presence of sounds within the uterus does not reflect what the fetus will actually hear, however. Conduction of sound through an air-filled external ear canal and middle ear chamber, the usual situation postnatally, would be significantly compromised when these chambers are filled with fluid. Experiments in pregnant sheep convincingly show a frequency-dependent attenuation of pure

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tones and noise reaching the fetal inner ear. The transmission path to the inner ear is through the bony structures of the head [5].

A logical extension of these single tone and noise experiments would be to determine how complex sounds, attenuated in their passage through the maternal abdominal wall, uterus and fluids surrounding the fetus, are further lessened in level within the cochlea. Findings would help us to understand what cues might be present in the spectral features of speech and music that would assist the fetus in carrying meaningful prenatal experiences into postnatal life.

2. METHODS

We followed the Guidelines for the Care and Use of Animals approved by the University of Florida. Two term pregnant ewes near term were anesthetized by mask with halothane, intubated, and maintained supine throughout the procedure with a mixture of oxygen and 2·0% halothane. The head of the fetus was exteriorized through a midline incision. An incision was made over the fetal bulla, caudal and posterior to the pinna, and the round window was located through the opened bulla.

An electrode was made from insulated stranded stainless-steel wire (Cooner Wire Co, Chatsworth, CA) with the insulation removed from one end. The uninsulated end was rolled into a 3-mm diameter ball and placed inside the round window niche (positive electrode) in one fetus. Rapid setting methyl methacrylate was used to secure the electrode and to close the bulla. Additional wires were sutured to tissue overlying the bulla (negative electrode) and to tissue at a remote site on the snout (ground electrode).

A miniature hydrophone (Bruel and Kjaer Model 8103, Marlborough, MA), used to detect intrauterine sound pressure level (SPL), was sutured to the fetal neck just below the pinna on one side of the fetal head. Calibration of the hydrophone was completed with a piston phone (Bruel and Kjaer Model 4223), and SPL was referenced to 20 μPa. All fetal incisions were closed. The fetal head was repositioned in the uterine cavity and the uterus and abdominal wall were closed. Ewes were carried on a stretcher to a sound attenuated booth and kept deeply anesthetized throughout the procedure on i.v. pentobarbital.

A second calibrated hydrophone was positioned over the ewe's abdominal midline. A loudspeaker (Peavey HDH-2) was placed laterally at a distance of 1 m and at the same height as the center of the ewe's flank.

At an earlier date, a recording of a trumpet sound was made in the sound booth of a series of six tones (E^3, A^3, $C^{\#3}$, E^4, A^4, $C^{\#5}$) representing fundamental frequencies of 170–560 Hz. The tones were played by a professional horn player. These tones were amplified and played through the loud speaker. Air and intrauterine recordings of these tones were made using a two-channel DAT instrument (Sony, model ZA5ES). The experiment was repeated using these same six tones as played on a flugelhorn. The entire experiment was repeated by recording the voltage output of the cochlear microphonic during both trumpet and flugelhorn playback of the six tones.

Recorded digital audio files were later analyzed with a computer program (Cool Edit Pro, Version 1.2, Syntrillium Softward Corp., Phoenix, AR). Fast Fourier Transforms (FFT) were calculated from several sound segments. Measurements of the sound pressure levels of the fundamental frequencies and overtones from the air and intrauterine hydrophones were made. The voltage outputs of the cochlear microphonic were similarly measured, at these observed frequencies. Additionally, the noise floor was measured during times before and after the playing of the tones. Inspection of the FFT of the CM revealed peaks that were only slightly above the noise floor. To confirm that these peaks coincided with the partials recorded in the air and uterine recordings of the tones, an analysis of the CM spectra was performed by $\frac{1}{12}$ octave constant bandwidth filters (Bruel & Kjaer Inst. Inc. Model 2123).

3. RESULTS

In Figures 1 and 2, we make a comparison between the air, intrauterine and cochlear microphonic (CM) outputs for both the trumpet and the flugelhorn during the playing of the lowest of our selected tones, E^2, with a fundamental frequency around 170 Hz. Over 12 partials can be seen rising above the noise floor for the air and uterus plots. At some overtone frequencies, the SPL in uterus exceed those in air for both trumpet and flugelhorn. At the highest tone played, $C^{\#5}$, similarities in the magnitudes of the air and uterus FFT peaks were also noticeable.

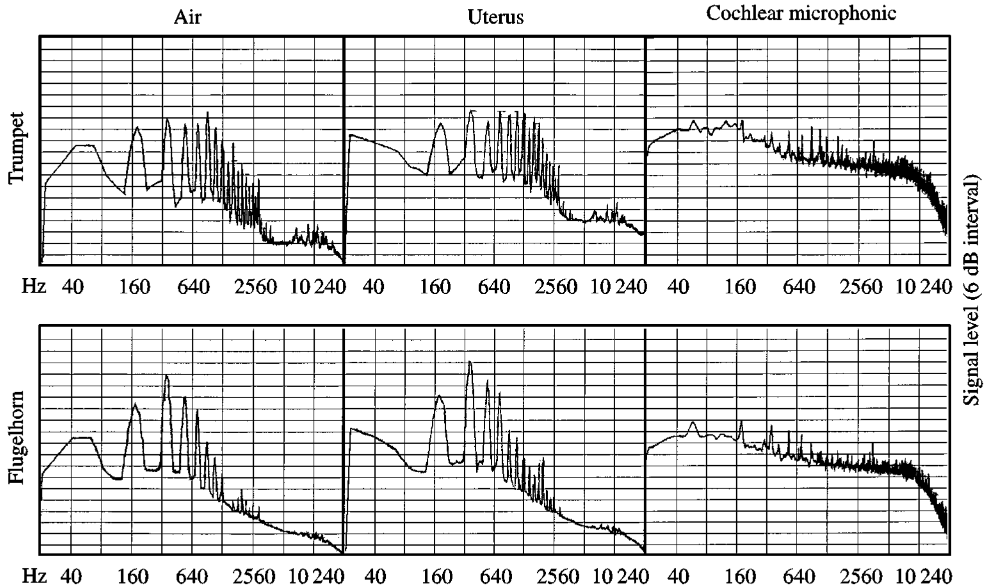

Figure 1. Frequency analysis using Fast Fourier Transform (FFT) of sustained trumpet and flugenhorn tones, $f^0 = 170$ Hz. The sound pressure levels are given for the air and uterus. The voltage output of the cochlear microphonic is expressed in relative dB.

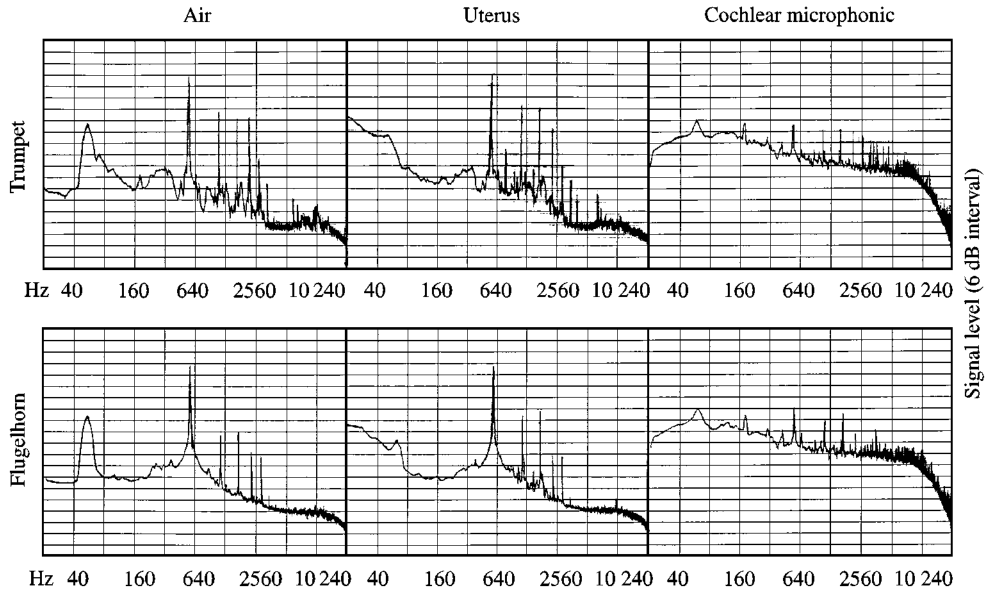

Figure 2. Frequency analysis using Fast Fourier Transform (FFT) of sustained trumpet and flugelhorn tone ($f^0 = 558$ Hz). The sound pressure levels are given for the air and uterus. The voltage output of the cochlear microphonic is expressed in relative dB.

Casual listening to the recorded intrauterine tones from both the trumpet and flugelhorn (played at levels of SPL at 100–129 SPL) indicates that the timbre of those instruments is preserved quite well, an impression supported by the presence of many partials seen in the FFT and $\frac{1}{12}$ octave band spectra.

FFT spectra of CM revealed up to three partials for E^3 and 4 partials for $C^{\#5}$. These partials coincided with the major peaks seen in the FFT and $\frac{1}{12}$ octave band spectra of air and uterine recordings (Figure 3).

4. DISCUSSION

There is now convincing evidence that the fetal environment is flavored with the multitude of sounds that surround its mother. Fetuses appear to develop a preference for sounds that will be relevant during early postnatal life. Behavioral studies show clearly that the soothing effects that music has on agitated and/or crying infants were developed during fetal life [6].

In the present paper we show the very efficient transmission of musical tones across the anterior abdominal wall, and through fluids and tissues comprising the abdominal and uterine contents. The fidelity of the musical tones as recorded in the uterus is determined not only by the presence of the air–tissue interface and the subsequent attentuation of partials in the higher frequencies (thus, the term "muffled" when describing the sound of external speech at normal levels as recorded *in utero*), but quite probably also by the position of the hydrophone within

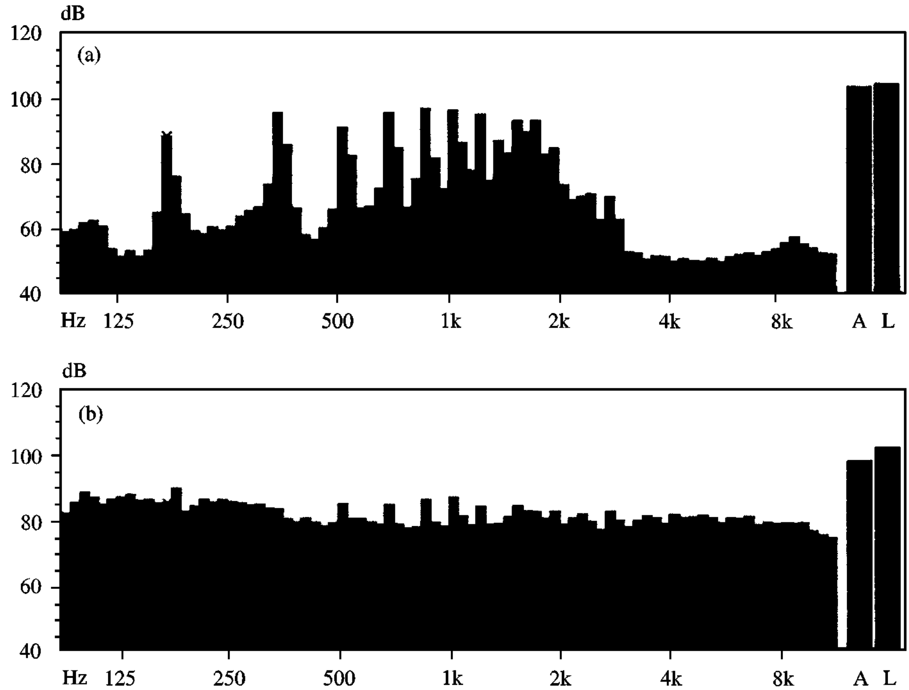

Figure 3. $\frac{1}{12}$ octave band frequency analysis of a trumpet playing E^3 (peak at 173 Hz) as recorded by (a) a hydrophone in the uterus and (b) by an electrode on the fetal round window (cochlear microphonic). The spectral peaks of the cochlear microphonic, although barely discernible above the noise floor, coincide with the fundamental and partials of the uterine recording.

the abdominal segment. The position effect is inferred from experiments in which sounds were produced by vibrators placed directly on the abdominal surface. The artificial electronic larynx, used commonly in fetal acoustic stimulation tests, produces small mechanical displacements of the abdominal skin in excess of 60 Hz. The overall spectral values may be up to 50 dB above those created when the device vibrates in air. In sheep, position-related SPL caused by vibrating objects can vary as much as 36 dB at a depth of 20 cm for a sinusoidal tone at 2000 Hz and as much as 30 dB at this same depth for a sinusoidal tone of 100 Hz [7].

Less is known about position-related attenuation of airborne sounds in the uterus. A thicker placenta and more subdermal abdominal fat characterizing pregnant women could increase the degree of sound attenuation primarily at high frequencies [8]. The signal level of the cochlear microphonic cannot be compared quantitatively with the signal levels of the air and intrauterine hydrophones. The signal-to-noise ratio is low, and the signal is often not distinguishable at all partials in a stationary plot of the FFT or $\frac{1}{12}$ octave band spectra. Nevertheless, viewers of the spectral displays as they are developing real time on the analyzer screen can often see the onset and cessation of the tones. Therefore, we speculate that rhythm, quite apart from the tonal attributes of the sound, is easily perceived by the fetus.

While listening to the cochlear microphonic (CM), without visualizing the development of the time waveform pattern, one was always able to identify the tone being played. From speech intelligibility studies it is known that a disadvantageous signal-to-noise ratio may only partially impede the intelligibility of speech. Presumably, the fetal perception of a musical tone would similarly be possible even though the external sounds are attenuated further by loss of amplification caused by a fluid-filled inner ear mechanism. The noise in the CM recordings is partially enhanced due to the high gain needed by the biologic amplifier in the processing of these signals. The signal-to-noise ratio in natural conditions may be better, indicating an even greater perception by the fetus of speech and music than implied in the present experiments.

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