

**THE TRANSMISSION OF MUSIC INTO
THE HUMAN UTERUS
AND THE RESPONSE TO MUSIC OF THE
HUMAN FETUS AND NEONATE**

**THESIS PRESENTED TO THE UNIVERSITY OF CAPE TOWN
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
BY
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DEDICATION

To my children

Dayne and Danielle

who were a major source of inspiration for this study.

DECLARATION

This thesis is the original work of the author, both in concept and execution. Apart from the normal guidance received from supervisors and consultants, no assistance was received. The ideas and results of the work of other authors mentioned in the text are fully referenced.

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Enough thanks cannot be expressed for the enormous volume of work done by Mr Nigel Coley on weekends, which extended beyond any reasonable expectations. The unenviable task of analysing hours of acoustic recordings, second by second, was completed with no hint of exasperation. His further assistance in procuring equipment, in manning equipment in the labour wards (despite his initial queasiness), in building a pressure transducer and in measuring tracings is gratefully acknowledged. My appreciation is expressed to Dr Adrien Jongens whom I consulted frequently on acoustic analysis of data and plagued with incessant questions; to Mr Dave Birch for conducting some intricate computer analysis of acoustic recordings; to Mr Peter Ranciman for his intellectual brilliance which provided answers by posing even more questions; to Mr Jean Knopperson who unselfishly contributed countless hours in procuring and calibrating acoustic equipment, conducting spectral analysis in pilot tests and agonising over the technical hurdles we faced. I further express appreciation to Dr Calum Delaney of the UCT Department of Logopaedics, for assistance in conducting pilot tests, the loan of equipment and for kindly sharing his expertise and knowledge. The support of several organisations in supplying equipment is gratefully acknowledged: The Institute of Maritime Technology, Simonstown; Protea Medical, Johannesburg; Anderson and Hurley, Johannesburg; the UCT Central Acoustics Laboratory; and the CSIR, Pretoria.

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My thanks to the mothers involved in the studies - without their cooperation this research would not have been possible; to the superintendents and medical personnel of the hospitals for their interest, practical assistance and their kindness in not making me feel that I was intruding, in particular Mr Mike Boyd of the Libertas Hospital and Ms Shirley Parker of Mowbray Maternity Hospital; to the childbirth

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**THE TRANSMISSION OF MUSIC INTO THE HUMAN UTERUS
AND THE RESPONSE TO MUSIC OF THE HUMAN FETUS AND NEONATE**

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ABSTRACT

The aim of this study was to investigate whether music influences human life before birth. In order to determine the existence and character of music in the uterine acoustic environment, a study was conducted involving the insertion of a hydrophone through the cervix, next to the fetal head. The investigation was conducted on eight women in early labour. The average residual uterine sound of the eight subjects was measured at 65 dBA (A-weighted) re 20 μ Pa in a 10 KHz band, RMS averaged over 32-second records. Above this emerged the maternal voice, an external female voice and a male voice presented at approximately 65 dB (linear weighted). Pure tones between 50 Hz and 10 KHz and orchestral music, all presented at 80 dB (linear weighted), were also shown to emerge above the residual uterine sound. Attenuation of external sound was observed to vary as a function of frequency, with less attenuation of lower frequencies. It was determined that the music was transmitted into the uterus without sufficient distortion to significantly alter the recognisable characteristics of the music.

The fetal heart rate (FHR) response to a music stimulus (MS) and a vibroacoustic stimulus (VS) was measured in 40 subjects. Gestational age of the fetuses ranged from 32 to 42 weeks. The study included a control period with no acoustic stimulation; a period with the presentation of 5 music stimuli; and a period with the presentation of 5 vibroacoustic stimuli. A change in the FHR of 15 beats per minute

or greater, lasting 15 seconds and occurring within 15 seconds of at least 2 of the 5 stimuli (or a tachycardia of greater than 15 beats per minute above the resting baseline, sustained for one minute or longer) was considered to be a positive response. The MS elicited a positive response in 35 of the fetuses (the 5 non-responses occurring in a period of low FHR variability) and all 40 fetuses responded to the VS (regardless of arousal state).

In the third study, mothers attending childbirth education classes volunteered to listen to a prescribed music excerpt twice daily from the 34th week of pregnancy. Ten neonates (all clinically normal) were tested between the 2nd and 5th day after birth. Investigators observed the effect of two music stimuli, the prescribed stimulus and a non-prescribed stimulus, on neonatal sucking of a non-nutritive nipple. A five-minute control period with no stimulation was compared with a ten-minute period during which two music stimuli were presented. By random allocation, either the prescribed music stimulus (PM) or the nonprescribed music (NM) was presented contingent upon sucking pressure. If a sucking burst was initiated, the PM stimulus was activated. On cessation of sucking, the NM stimulus was activated. Randomly, the procedure would be reversed for some of the subjects, where initiation of sucking activated the NM stimulus and cessation of sucking activated the PM stimulus. It was determined that the inter-burst intervals during the music period were significantly extended when coinciding with the PM stimulus and significantly shortened when coinciding with the NM stimulus.

The studies indicated that music is transmitted into the uterus with insufficient distortion to alter the character of the music; that the normal fetus responds to a music stimulus from at least the 32nd week of gestation; and that the neonate alters the normal sucking pattern to activate longer periods of a music stimulus which has been repeatedly presented during the intrauterine stage and shorter periods of a novel music stimulus.

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INTRODUCTION

Mankind is musical. Inherent in one's being human is the ability to perceive music and furthermore to respond to, discriminate, remember, interpret and imitate (to a greater or lesser degree) the music within one's environment. Every normal human being is musical, in that he or she possesses basic discriminational senses of pitch, timing, dynamics and timbre.

"Musicality is a complex function involving the special senses and intellectual and emotional functions" (Henson 1977 p9).

The power of music on human intellect, aesthetic experience, spiritual experience, imagination, emotion, state of mind and autonomic function is well-known. Music, created in the realms of the cognitive and, frequently, emotional and spiritual spheres, is transferred by the physical means of the sound wave and has the power to communicate with and influence the same spheres in the listener. Music may be perceived without any knowledge of the physics, physiology or psychology involved in the process, making it accessible to every normal person. However, man's listening, composing and performing abilities may be developed to vastly differing degrees. Whether these are the product of genetic endowment, environmental influence, or a combination of both, is a subject of constant debate (Pratt 1977, Suzuki 1981).

"Musical talent is first an inborn capacity. Artistic musical performance rests ultimately on innate, inborn equipment" (Schoen 1940 p161).

"There is no such thing as an inheritance of capacity, talent, temperament, mental constitution and characteristics" (Allport 1937 p103).

"It is now clear that neither nature nor nurture alone can make a musician. Both must be present before musical and other abilities emerge" (Farnsworth 1969 p156).

Evidence of music as a component of every human culture is found throughout recorded history (Nettle 1975, Radocy and Boyle 1979, Hamm et al. 1975, Farnsworth 1969, Merriam 1964, Lundin 1967). The powers of music have been well respected in civilisations since the pre-Christian era. Modern western man's experience of music is progressively more passive than active, due to the availability of audio recording and play-back systems. In the idolisation of scientific and technical knowledge, music has been relegated to the status of an optional 'extra-mural' study in some education systems. The folly of this blindness to the wholistic needs of the child may yet be exposed. Besides cultivating cognitive appreciation of the aesthetic aspect of music and developing listening and performing skills, the possibilities for meeting and fostering the emotional sensitivities and passions of children through music experience are vast.

"Our subject is not music as an abstract art, but music as a force which affects all who hear it. Music - not as entertainment only, but as a literal power. Whenever we are within audible range of music, its influence is playing upon us constantly - speeding or slowing, regularizing or irregularizing our heartbeat; relaxing or jarring the nerves; affecting the blood pressure, the digestion and the rate of respiration. Its effect upon the emotions and desires of man are believed to be vast, and the extent of its influence over even the purely intellectual, mental processes is only just beginning to be suspected by researchers" (Tame 1984 p13).

At what age is the developing human life sufficiently mature to be able to perceive music and be influenced by it? The continued use of the soporific lullaby over the ages attests to the concept that the neonate responds to music. Rhythmic rocking is a phenomenon of motherhood crossing time and continents. It is frequently heard that pregnant women observe changes in fetal movement patterns when exposed to

INTRODUCTION

certain sounds, such as sudden noise or music. The paucity of research publications pertaining specifically to fetal and neonatal experience of music is contrasted by the wealth of medical research into the effects of sound (such as noise, pure tones, etc.) during this early stage of development.

Whether the fetus and neonate are capable of experiencing music; in what realms of consciousness or subconsciousness that experience occurs; how music is perceived (cognitively, psychologically, etc); and whether learning is an inherent product of that experience, are issues which need to be addressed. There are many other questions relating to the subject. Is musical influence on the fetus and neonate restricted to physiological effects or does it also influence the cognitive, emotional and spiritual spheres; at what stage are auditory learning and memory present; when does music conditioning begin and how significant are the initial stages in the music learning process?

To answer these questions requires a knowledge of the intrauterine acoustic environment and the fetal and neonatal capacity to hear and process auditory information. While the author has not endeavoured to exhaust the almost infinite possibilities for researching this field, three crucial aspects are addressed:

1. The transmission of music into the human uterus.
2. The response of the normal human fetus to a music stimulus.
3. The response of the normal neonate to a music stimulus which has been repeatedly presented during the intrauterine stage.

Music involves, at any moment, the composer, the performer and the listener. One individual may fulfil one, two or all three functions, or the number of persons may be multitudinous. In the light of work by educationalists such as Ostwald (1973), Fridman (1989) and Lind (1980) who claim that the baby's first cries are his or her first musical expressions (with characteristic pitch, frequency and rhythm), it may be erroneous to assume that the fetus and neonate are not involved in the composing or performing of music. However, because of the severe limitations of current knowledge regarding this theory, the author restricts observations to the fetus and neonate as listeners.

The rationale for the literature review and the pursuance of the three research projects lies in the need to determine whether the human fetus and newborn infant are exposed to the influence of music. This study requires investigation into the following:

THE TRANSMISSION OF MUSIC INTO THE UTERUS

Fetal perception of sound must, of course, be restricted to the sounds which exist in the intrauterine acoustic environment. A review of the literature provides an indication of the characteristics of sounds within the uterus which are of physiological origin, as well as external noise, pure tones and human vocalisations which emerge above those sounds. Various theories exist regarding the character of music which is transmitted into the uterus. It may be argued that music does not exist in the uterus, based on the theory that only exceptionally loud sounds (such as, a nearby jet aircraft) can emerge above the uterine sounds (Walker et al. 1971). Another claim has been made that the fetus is exposed to only the higher frequencies of music (Tomatis 1981). Determining the presence and quality of music in the fetal acoustic environment is a prerequisite for understanding the possibilities of musical influence on the fetus. The results of intrauterine recordings made by the author, during which music was presented externally, are delineated in this document.

THE ONSET OF THE HEARING FUNCTION IN THE HUMAN FETUS

By examining the literature regarding the embryological development of the ear and the central nervous system, it is possible to estimate the onset of auditory function in the human.

FETAL AND NEONATAL RESPONSE TO MUSIC

The study of fetal and neonatal sensory perception provides further indication of the onset of human auditory function.

INTRODUCTION

"Perceptual development has been one of the most rapidly expanding areas of investigation over the past two decades. A number of factors have converged to make this possible: the dissemination of Piagetian theory and data, the application of ethology to human behavior, the redemonstration by Fantz (originally demonstrated by the German psychophysicists) that even the newborn can be cajoled into answering interesting research questions, improvements in both technology and methodology, and finally, striking recent advances in developmental neurophysiology. Although isolated reports of the infant's ability to see and hear date back to the nineteenth century, it has only been within the last few years that investigators have begun comprehensive programmatic examinations of early sensory, perceptual, and cognitive systems. What has emerged is a view of the infant as a curious blend of neural-behavioural systems - reflex and voluntary, sensory and perceptual, sensorimotor and representational" (Cohen and Salapatek 1975 p ix, x).

A plethora of examples in the medical literature indicate fetal and neonatal response to acoustic stimulation, while scant attention has been paid to response specifically to music. Research by the author investigates fetal response to a music stimulus.

FETAL AND NEONATAL AUDITORY DISCRIMINATION, MEMORY AND LEARNING

While evidence of fetal response to music is a significant discovery, the question remains of how music sounds to the fetus. Can the fetus discriminate different tones, rhythms, timbres, etc? Is there, consequently, sensitivity to the differences between noise, voices or music? Music exists in the passage of time. Whether the fetus ever hears more than a momentary musical sound, unrelated to any other, needs investigation. If it is to be concluded that the fetus is capable of hearing music as a sequence of acoustic events, then it is necessary to determine fetal discrimination and memory of sound. Investigation into fetal and neonatal auditory learning and conditioning provides significant information regarding the influence of music on the human

from the prenatal stage. A review of the literature, as well as research by the author specifically pertaining to music, provides an indication of auditory discrimination, memory, learning and conditioning in the fetus and neonate.

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SECTION 1

LITERATURE REVIEW

CHAPTER 1

THE INTRAUTERINE ACOUSTIC ENVIRONMENT

How early is human life influenced by music? A study of the subject from the fetal stage requires investigation of whether some form of inherent music exists in the uterus (such as, rhythmic systolic sounds or the sound of the mother's voice) and whether external music penetrates the intrauterine acoustic environment. The issue of fetal hearing capabilities (including the arguments relating to the vibration of sound in a fluid medium, and the viscous and hydrodynamic features of the ear described in chapter 2) is crucial in the establishment of fetal experience of music. However, it is first vital to determine whether externally-presented music is modified during transmission into the body and how this affects the character and quality of the music.

The paucity of literature on the subject reflects the difficulties involved in conducting this research. Intrauterine acoustic recording requires a relatively invasive procedure, thus restricting the number of subjects tested in any investigation. Researchers are further limited by the use of acoustic recording equipment which has not been specifically designed for this purpose. In some cases, recordings have

been conducted using a miniature microphone, covered by a rubber sleeve, which is inserted into the uterus. Other studies have involved the use of a hydrophone (which is a microphone designed specifically for use in a fluid medium) and the researcher has been obliged to work with the sensitivity levels peculiar to hydrophones which are of suitably small magnitude. The data made available from the few relevant publications provides a description of the intrauterine acoustic environment (1.1) and the transmission of certain external sounds into the uterus (1.2).

1.1 THE RESIDUAL INTRAUTERINE ACOUSTIC ENVIRONMENT

Placing a microphone (enclosed in a rubber membrane) in the vagina of one pregnant human patient, at a location against the cervix, Bench (1968) measured a sound pressure level of 72 dB (linear weighted) (appendix 1.1). Rhythmic peaks were regarded as being of vascular origin. A similar test, conducted four weeks after delivery, determined no rhythmic pulsations. It was therefore assumed that those peaks in the sound pressure level which occurred during pregnancy originated from the uterine blood vessels (the uterine artery being adjacent to the cervix). A later study was conducted on 16 women in labour by Walker et al. (1971), involving the insertion of a condenser microphone (covered by a rubber sleeve) into the uterus, at a location near the fetal ear. The mean intrauterine noise level was measured at 85 dB re 20 μ Pa (linear weighted), with peaks of 95 dB occurring simultaneously with the maternal pulse. An error of 10 dB was estimated and the mean sound pressure level was converted to 95 dB. There was no significant difference between measurements taken before rupture of membranes (with microphone placed in the cervical canal adjacent to the fetal head) and after rupture of membranes (with microphone lateral to the fetal head and close to the ear).

Henshall (1972) used a phonocatheter, with a small diaphragm and coil at its tip, to examine intrauterine sound levels in 12 human subjects. The microphone was not as sensitive as those used in other tests reviewed in this chapter. Insertion took place after rupture of membranes. Amplifier noise was measured at a sound pressure level of 96 dB, relative to 20 μ Pa. Occasional vascular sounds and maternal borborygmi were barely audible above this.

The study of intrauterine sounds in humans by Querleu et al. (1981) appears to be more accurate than those conducted by previous researchers, owing to the use of a hydrophone. The procedure was conducted on three women in active labour, after the rupture of membranes. The baseline intrauterine sound was found to consist of a predominantly low-frequency noise, above which emerges vascular and intestinal sounds. The following average measurements, taken over a 16-second period, were observed:

FREQUENCY	SOUND PRESSURE LEVEL	
	LINEAR WEIGHTED	A-WEIGHTED
12.5 Hz	87.4 dB	19.4 dB(A)
100.0 Hz	58.0 dB	39.0 dB(A)
250.0 Hz	55.3 dB	46.3 dB(A)
1 000.0 Hz	58.7 dB	58.7 dB(A)
5 000.0 Hz	59.2 dB	60.2 dB(A)

The high average sound pressure level, measured at 89 dB (linear weighted) is mainly attributable to the lower frequencies, with much lower levels above 100 Hz. Benzaquen et al. (1990) confirmed these results, also using a hydrophone. The test was conducted on 10 subjects in labour, after rupture of membranes. The mean absolute intrauterine sound pressure level predominantly consisted of low-frequency noise of up to 85 dB re 20 μ Pa (linear weighted) below 100 Hz. Above 100 Hz, this level was less than 60 dB and above 500 Hz, only 40 dB. No significant difference in sound pressure levels was observed between uterine contraction and uterine relaxation. No cardiovascular sounds were audible in 8 of the 10 women tested, and in the other two, they were not audible during uterine contractions. Bowel sounds were audible in three subjects. Smith et al. (1990) tested 9 subjects after rupture of membranes, by placing a microphone, covered with latex and an elastic band, into the uterus to a position adjacent to the anterior fetal ear. Baseline levels ranged between 72 dB and 88 dB (assumed to be linear weighted and referenced to 20 μ Pa). A test by Arulkumaran et al.

(1992) involved the placement of a hydrophone close to the lateral aspect of the fetal head, after the rupture of membranes. The mean intrauterine sound pressure level was determined to be 65 dB re 20 μ Pa (linear weighted).

1.2 THE TRANSMISSION OF EXTERNAL SOUNDS INTO THE UTERUS

The transmission of sound from one medium to another results in attenuation (loss of sound pressure) as a result of the impedance mismatch. External sounds are shown to attenuate as a function of frequency during transmission into the uterus. Bench (1968) measured attenuation of pure tones to be 19 dB (linear weighted) at 200 Hz, 24 dB at 500 Hz and 38 dB at 1000 Hz. Presenting sine waves, Walker et al. (1971) measured attenuation levels of 33 dB (linear weighted) at 200 Hz, 39 dB at 500 Hz and 51 dB at 1000 Hz. Measurements taken before and after rupture of the uterine membranes produced no significant difference between readings. The authors speculated that only few external sounds (such as a nearby train or aircraft) are able to exceed the intrauterine sound level.

Delivering an external white noise stimulus at 110 dB, Querleu et al. (1981) confirmed that less attenuation occurs at lower than at higher frequency levels, with only 2 dB (linear weighted) attenuation at 250 Hz, rising to 14 dB at 500 Hz, 20,4 dB at 1000 Hz and 26 dB at 2000 Hz. An intrauterine recording determined the emergence of the maternal voice, uttered at 60 dB. Its highest emergence was at the frequency level of 200 Hz, measured at 12,5 dB above residual intrauterine sounds. Male and other female voices emerged at slightly lower sound pressure levels. Benzaquen et al. (1990) determined the emergence of the maternal voice by 20 dB (linear weighted) above residual uterine noise, with peak levels at 200 Hz to 250 Hz. In a letter to the British Journal of Obstetrics and Gynaecology, Querleu et al. (1986) explained that analysis of a nursery rhyme revealed an exact reproduction of the pitch curve of the voices on the intrauterine recording. Thirty percent of the French phonetic sounds were determined to be recognisable.

The study by Arulkumaran et al. (1992) involved the presentation of broad band spectra signals produced by a fetal acoustic stimulator (Corometrics

Medical Systems, Connecticut, USA) commonly used in the assessment of fetal well-being. The sound pressure level of the vibroacoustic stimulator recorded in air was specified as 107 dB (linear weighted) at 2 cm distance and 74 dB at 1000 cm. When held in direct contact with the maternal abdomen, the mean intrauterine sound pressure level was 90.7 dB (linear weighted). When holding the stimulator 2 cm above corresponding sites, this level was measured at 80.1 dB. The study by Smith et al. (1990) determined intrauterine sound pressure levels of 92 dB to 111 dB (linear weighted) during presentation of a vibroacoustic stimulus delivered by a model 5C electronic artificial larynx. These results are in contrast to the much higher intrauterine sound levels determined in sheep, during the presentation of vibroacoustic stimuli. Gerhardt et al. (1988) measured levels as high as 135 dB (linear weighted) when the hydrophone was placed directly below a vibroacoustic stimulus delivered by an artificial larynx (Bell Telephone Model 5-C, Western Electric, New York, N.Y.). Moving the stimulus laterally on the maternal abdomen, to a position 6 inches away from the hydrophone, caused a drop in sound pressure level to 101 dB. Richards et al. (1991) determined that the average sound pressure level in 4 sheep during the presentation of a vibroacoustic stimulus (delivered by an electronic artificial larynx, model 5C, AT& T Consumer Products, Parsippany, N.J.) was 119 dB (linear weighted), with the hydrophone placed 5 cm from the abdominal surface. Increasing the depth of the hydrophone to 20 cm below the surface caused a drop in the level to 102 dB.

1.3 DISCUSSION

Rhythm, a fundamental component of music, is shown to be a prominent feature of the uterine acoustic environment where systolic sounds emerge above ambient noise. Some error can be expected in the results of studies using a microphone requiring a protective rubber sleeve, due to the attenuation of sound which would have occurred as a result of the impedance mismatch between each of the fluid/rubber/air interfaces. Residual intrauterine measurements, obtained by means of a hydrophone, have been determined at similar sound pressure levels in the studies by Benzaquen et al.

(1990) and Querleu et al. (1981), but results differ in the study by Arulkumaran et al. (1992). The frequency range analysed in the latter is not specified, and may be responsible for this difference. The measurements of sound pressure levels in the human intrauterine acoustic environment probably give a false impression of the level which may be experienced by the fetus. The high sound pressure level is mainly contributed by the lower frequencies, to which the human ear is less sensitive. When converted to the A-weighted measurement scale (appendix 1.1), which corresponds more accurately with human hearing abilities, the level of 89 dB (linear weighted) becomes 65 dBA (A-weighted), about the level of normal conversation.

The maternal voice emerges above residual uterine sounds at a higher sound pressure level than external voices because it is conducted directly through the body, as well as through surrounding air (the latter involving a high degree of impedance mismatch).

Based on studies of the transmission of white noise, pure tones and voices into the uterus it may be assumed that music is transmitted into the uterus. However, considering the attenuation of external sounds which occurs as a function of frequency, it may be hypothesised that the original character of the music is distorted during transmission into the uterus.

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THE DEVELOPMENT OF AUDITORY FUNCTION IN THE HUMAN FETUS AND NEONATE

In determining the onset of hearing in the human fetus, it is necessary to examine the structural maturity of the developing ear, the establishing of its link to the brain through the central nervous system and evidence of electrical activity of the brain stem and cortex. A summarised anatomy of the ear (2.1), with illustrations, provides a context for the investigation into its embryological development (2.2). A concise summary from the literature on the embryology of the human auditory system describes the stages at which each section of the ear reaches maturation (Hamilton et al. 1972, Williams et al. 1989, Langman 1981, Moore 1983). Illustrations were redrawn from Moore (1983), Netter (1983), Thibodeau (1987), Snell (1978) and Langman (1981). The mechanical process of hearing is explained (2.3.1) in order to illustrate the essential role of each part of the ear, followed by a brief overview of normal human hearing ability (2.3.2). Some issues specifically regarding fetal and neonatal hearing are addressed (2.3.3). Based on the evidence presented, a conclusion is drawn regarding the probable stage at which human hearing commences.

2.1 THE ANATOMY OF THE HUMAN EAR

The ear is partly situated on the outer side of the skull, with the remaining structures encased within the petrous temporal bone (fig 2.1). The ear has

three distinct anatomical parts, these being the internal ear, the middle ear and the external ear.

2.1.1 The external ear

The external ear includes the auricle, which consists of skin-covered fibrocartilage, protruding outwards from the side of the head and the external auditory meatus, a canal which leads from the auricle into the skull (fig 2.2). The tympanic membrane separates the external and middle ear. Consisting of fibrous tissue, it is lined externally with stratified squamous epithelium and internally with simple cuboidal epithelium.

2.1.2 The middle ear

The middle ear is comprised of the tympanic cavity, the auditory ossicles, the eustachian tube and the mastoid air cells. The small tympanic cavity, situated in the temporal bone contains the auditory ossicles. The malleus is attached by its handle to the tympanic membrane while its head is joined to the upper part of the incus. The lower end of the incus is joined to the stapes (fig 2.3).

The inner wall of the middle ear cavity has an oval window, to which the footplate of the stapes is attached, and a round window closed by a membrane (fig 2.4). The eustachian tube leads from the tympanic cavity to the nasopharynx, allowing for a passage of air between the pharynx and middle ear. An opening leads backwards from the tympanic cavity into the mastoid antrum and the air cells of the mastoid process (fig 2.5).

2.1.3 The internal ear

The internal ear contains the membranous labyrinth which is encased in the bony labyrinth. The bony labyrinth is a system of bony cavities and canals consisting of the cochlea, vestibule and semicircular canals.

The vestibule leads anteriorly into the coiled cochlea while three semicircular canals open into the upper part of the vestibule.

Between the bony labyrinth and the membranous labyrinth, which is contained in it, is a layer of perilymphatic fluid. In the vestibule lie two membranous vesicles, the sacculle and the utricle. These contain sensory hair cells which are connected to the auditory nerve. The endolymphatic duct connects with the lower end of the sacculle. The sacculle is anteriorly linked to the membranous cochlea (fig 2.6).

A cross section of the membranous cochlea reveals a basilar membrane and a vestibular membrane which run the length of the cochlea. Between these two membranes lies the cochlear duct, while on their outer sides lie two perilymphatic spaces. These are called the scala vestibuli and the scala tympani. The spiral ligament connects the outer margin of the basilar membrane to the surrounding cartilage. Inside the cochlear duct are the sensory cells, essential to the auditory process. They include inner and outer rows of hair cells and, together with several other cell types and the covering tectorial membrane, they are known as the organ of Corti. Auditory nerve fibres of the eighth cranial nerve enter through the spiral ganglion and reach the rows of hair cells (fig 2.7).

2.2 THE EMBRYOLOGICAL DEVELOPMENT OF THE EAR

The ear shows first signs of development in the embryo of approximately 3 weeks. Apart from the mastoid air cells, the ear has reached an advanced state of development by the 24th week.

In the early stages of embryonic cell division, the neural groove appears giving rise to the five pharyngeal pouches, with their arches and grooves (fig 2.8). In this region the three divisions of the ear develop as separate structures which later function in association with one another. The internal ear initially develops at the side of the hindbrain, while the middle ear appears at the first

pharyngeal pouch. The external ear develops in the region of the first pharyngeal cleft.

2.2.1 The internal ear

This is the first division of the ear to develop, appearing from as early as the third week. A thickening of ectoderm (known as an otic placode) appears on the side of the embryo, near the hindbrain, above the first pharyngeal groove (fig 2.8). This invaginates by the end of the 3rd week, forming an otic pit. The mouth of the pit closes in the 4th week, leaving a pear-shaped cavity called the otic vesicle (fig 2.9).

In the 5th week, a hollow tube protrudes from this vesicle, forming the endolymphatic duct. A week later, two divisions in the vesicle become apparent: the utricular and saccular portions (fig 2.10). The saccular portion gives rise in the 6th week to a tubular outpocketing which becomes the cochlear duct. From the utricular portion emerge three flat disc-like outpocketings. The central walls of the disc-like diverticulum fuse and disappear, giving rise to three semicircular canals. The cochlear duct coils into the surrounding mesenchyme. By the 8th week, it has spiralled two and a half times with only a narrow ductus reuniens connecting it to the saccule (fig 2.11). The mesenchyme surrounding the inner ear structures become cartilage. By the tenth week, cavities appear in the cartilage around the cochlear duct, forming the two perilymphatic spaces, the scala vestibuli and the scala tympani. The cochlear duct is then suspended between these two fluid-filled spaces. Inside the cochlear duct, the organ of Corti develops on the basilar membrane which separates the duct from the scala tympani. The eighth cranial nerve attaches to the cochlear duct in the 11th week. The inner and outer hair cells are formed by the 12th week and are covered by the tectorial membrane. The development of the auditory nerve fibres and spiral ganglion at this time brings the formation of the membranous labyrinth to completion (fig 2.12). The cartilage surrounding the inner ear structures begins to ossify, forming the petrous temporal bone and bony labyrinth.

2.2.2 The middle ear

Development of the middle ear occurs from the 4th week, in the region of the first pharyngeal pouch which has dilated to form the tubotympanic recess. The distal end gradually dilates, becoming the tympanic cavity, while the proximal portion forms the Eustachian tube. In the 7th week, the mesenchyme alongside the tubotympanic recess becomes condensed to form a number of masses of cartilage. The malleus and incus, which are derived from the mesoderm in the first pharyngeal arch, are present in the cartilage from the 8th week. Also at this time, the lower half of the tympanic cavity (the eustachian tube) is formed. The tympanic cavity extends dorsally by a process of vacuolization of the surrounding tissue, beginning to envelop the ossicles. The cartilagenous stapes (derived from the second pharyngeal arch) forms by the 15th week. The malleus and incus begin ossification in the 16th week, while the stapes ossifies from the 18th week. These ossicles are of adult size. The ossicles remain embedded in the mesenchyme until the 24th week, when the surrounding tissue dissolves, to be replaced by the expanding tympanic cavity (fig 2.13).

In late fetal life, the tympanic cavity extends to form the antrum. While some mastoid air cells appear in the 34th week, most of these cells only begin to develop after birth, in a process called pneumatization. The mastoid process is not present at birth and has its greatest period of growth between the third year and puberty.

2.2.3 External ear

The external auditory meatus develops as thickenings of tissue at the dorsal end of the first pharyngeal cleft, from the 4th week. The internal auditory meatus inverts from the 5th week. By the 8th week, the outer cartilagenous third of external canal is formed. The tympanic membrane is formed by the ectodermal epithelial lining of the meatus and the endodermal epithelial lining of the tympanic cavity. Mesenchyme of the first and second branchial arches grows between

the linings and differentiates into fibrous stratum. By the 9th week, three tissue layers are present in the tympanic membrane. At this time, the ectodermal cells at the bottom of the meatus proliferate and extend inwards as a solid cylinder, called the meatal plug. The meatal plug disintegrates from the 28th week, leaving the definitive external auditory meatus and exposing the tympanic membrane.

The auricle is derived from six auricular hillocks (swellings) which appear during the 6th week at the first and second pharyngeal arches. They are produced by proliferation of mesenchyme on either side of the external meatus. As formation of cartilage begins, the hillocks develop and fuse forming the auricle while gradually moving from the neck region to the level of the eyes (fig 2.14). By the 20th week the auricle has acquired its final shape but continues to grow until 9 years of age.

2.3 HUMAN HEARING FUNCTION

The ear has two functions, the first being hearing and the second, balance and the detection of movement. The saccule, utricle and semicircular ducts are responsible for the latter, while the external ear, the middle ear and the cochlear duct are instrumental in the hearing process. The second function is not addressed in this chapter as it has no bearing on the hearing process.

2.3.1 The physiology of hearing

A sound source is a vibrating system which has been set in motion by a form of energy. These mechanical oscillations cause a series of oscillating movements in the surrounding particles of matter. Although no overall movement may take place in the medium, the molecules themselves vibrate and the energy is transferred to the surrounding molecules.

Vibrations which reach the auricle are, because of its shape, directed towards the external auditory meatus, while others may be transferred through the skull and body. The resonances of the external ear

increase the sound pressure at the tympanic membrane. At certain frequencies the auricle plays an essential part in the process of sound localisation.

The vibrating air molecules in the external auditory meatus set the tympanic membrane in motion. The eustachian tube in the inner ear links the tympanic cavity with the nasopharynx, allowing air to reach the inside of the tympanic membrane. It is necessary for air to equalise the pressure on both sides of the membrane, so that it can vibrate freely. The middle ear transfers these vibrations to the cochlea and in the process, acts as a transformer by matching the low impedance of the air in the auditory meatus to the higher impedance of the cochlear fluids. The function of the mastoid air cells is unclear, as their surgical removal does not affect the hearing process. Before birth, there is obviously no air surrounding or in the ear.

The malleus, which is attached to the inner side of the tympanic membrane, transmits vibrations to the adjoining incus and stapes. Impedance matching is largely due to the difference in area between the larger tympanic membrane and the small footplate of the stapes. Pressure is consequently increased at the cochlear wall. The footplate of the stapes is elastically fitted to the flexible oval window in the wall of the cochlea. Vibrations are transferred through this window to the perilymphatic fluid in the inner ear. The elastic membrane of the round window reacts to any compression of the fluid and gives way, returning to its former position when the stapes is pulled outwards again. This causes oscillatory movements in the fluid of the cochlea, which result in a wave-like displacement of the basilar membrane and the structures attached to it. As the basilar membrane moves up and down, relative movement occurs between the tectorial membrane and the organ of Corti, causing lateral displacement of the cilia. The auditory nerve fibres, which are attached to the base of the hair cells, transmit neural impulses corresponding to these movements through the spiral ganglion. They are carried along the eighth cranial nerve and passed up the brain stem to the cerebral cortex.

2.3.2 Human hearing abilities

The normal human ear should be able to distinguish frequencies between 20 Hz and 20 KHz (Sharland 1972). This falls within the range of 10^{-12} and 10^2 W/m². A graph of the normal frequency range of human hearing capabilities, with relevant sound pressure level thresholds, is located in the appendix (fig A1.2). Although the ear is capable of hearing extremely soft sounds, these are generally masked by environmental sounds. Under special circumstances, such as may be experienced in an anechoic chamber, the human ear can detect sounds as soft as the bumping of air molecules on the eardrum (Everest 1981). The eardrum motion resulting from this sound is only one hundredth of a millionth of a centimeter. Such a chamber is usually built underground with thick walls, ceiling and floor, lined by three-foot glass fibre wedges pointing inwards. The room has a suspended steel grillwork on which one can walk. Compared with normal environments, this chamber appears to be oppressively silent. At the other extreme, the human ear is capable of hearing jet aircraft. While the ear has certain features to protect itself from high sound pressure levels, loud sounds can cause permanent damage to the ear, depending on the frequency, dynamic level and duration of sounds. Repeated exposure to more than 85 dB for longer than 8 hours has been suggested by the Occupational Safety and Health Administration to cause permanent hearing loss (Silverman 1989).

The human ear perceives frequencies of different intensities to be of equal loudness (as represented on the equal loudness contours illustrated the appendix) (fig A1.2). The human ear is more sensitive to the frequencies which are important for the detection of speech, with less sensitivity at the higher and lower extremes of the frequency scale.

A person is capable of interpreting sound in terms of localisation, pitch, timbre, loudness and duration. By discriminating frequency, humans are able to perceive melody (a series of pitches sounding one after the other), harmony (a combination of simultaneously-sounded pitches)

and timbre (which is determined by the particular harmonics which accompany pure tones, providing the distinguishing characteristics of particular musical instruments). The ability to determine duration of sound (by remembering the onset, endurance and cessation of sound) enables the human to perceive rhythm and pulse. Loudness perception enables the human to determine the dynamics (varying levels of intensity) of music although, as explained, the interpretation of intensities is not always equivalent to the intensities presented. The discrimination of melody and rhythm/pulse, and the ability to relate any dynamic level, pitch, melody, harmony or timbre to any heard previously are dependent on auditory memory. Humans normally possess the capacity for auditory imagery, enabling them to remember, anticipate or compose music in their imagination.

2.3.3 Fetal and neonatal hearing function

In 1885 Preyer stated "with almost certainty" that the infant has no developed sense of hearing before birth. Besides histologic evidence now available, recent research into behavioural, autonomic and electroencephalographic responses of the fetus and neonate provides overwhelming indication of auditory function from the prenatal stage.

With regard to fetal hearing of externally-presented sounds, account must be taken of the attenuation which occurs when the sound is transmitted from the air through the body, as a result of the impedance of the fluid environment (chapter 1). Various theories have been published regarding fetal hearing function, including the theory of fluid in the middle ear hindering the transmission of sound via the impedance process of the ossicular chain (Hamilton and Mossman 1972, Gagnon et al. 1986b, Arulkumaran et al. 1992). The study by Arulkumaran et al. (1992) addresses issues involved in the process of fetal hearing of externally-presented sounds, stating that the fluid in the fetal middle ear represents a situation similar to the fluid-filling which occurs in effusive otitis media, causing a hearing loss of 20 dB. However, it must be pointed out that the sound in the fluid environment

of the uterus is well-coupled to the fluid of the cochlea and it is cautioned that the possibilities of sound being transmitted by means of bone conduction, by-passing the ossicular chain and coupling via the round window need extensive research before conclusions can be drawn regarding fetal hearing.

According to Littler (1965), resonant frequencies occur in the adult middle ear at 1200 Hz and 800 Hz and in the external ear at 3000 Hz. It is suggested by Hecox (1975) that the resonant frequencies of the ear may be altered by the dimensional changes of the middle and external ear cavities which occur with age, thus altering frequency sensitivity.

Myelination of the eighth nerve is more advanced than that in other cranial nerves, apparently being complete by birth. Conduction velocity is increased in myelinated nerve fibres, resulting in decreased latencies. Previously, myelination was presumed to be so insufficiently developed in the neonate that only rudimentary sensory and motor responses could be expected (Peiper 1963). The eighth cranial nerve is capable of responding before the structural maturity of the cochlea is attained (Marty and Thomas 1963). While the lower brain stem is well myelinated before birth (Yakovlev and Lecours 1967), incomplete myelination of the inferior colliculus and medial geniculate body exists at birth (Rorke and Riggs 1969). Functional maturation of the fetal autonomic nervous system appears to have been achieved by the 28th week of gestation, indicated by the fetal heart rate, eye blink, facial, limb and body movement responses to vibroacoustic and acoustic stimulation observed from the beginning of the third trimester (Druzin et al. 1989, Kuhlman et al. 1988, Leader et al. 1982a, Gelman et al. 1982, Tanaka and Arayama 1969).

Studies of human brain maturation indicate that brain function depends on several factors:

"number and location of neurons in the brain; degree of differentiation of these neurons: structure, metabolism; ability of neurons to generate action potentials, spontaneously or

when stimulated; number of synapses between neurons and their targets; differentiation of synapses; organisation of the total network for sensory reception, information processing and action responses" (Herschkowitz 1988 p 3).

A major period of neuronal proliferation is estimated to occur from 15 to 25 weeks gestation, ending at about 3 - 4 years (Dobbing and Sands 1970). Neuronal migration results in the first layer of the cortical plate being present at 8 weeks. By 12.5 weeks, a subplate, which will later form the deeper layers of the cortex, is present (Molliver et al. 1973). These layers are clear by 28 weeks. By 32 weeks, they have the same appearance as those of older children (Herschkowitz 1988). From 9 weeks, neuromuscular junctions appear and, by 20 weeks, motor endplates can be observed (Goudsouzian and Standart 1986). The presence of synapses have been identified by Molliver et al. (1973) in the cerebral cortex (above and below the cortical plate) of fetuses from 8.5 weeks gestation, demonstrating how early the establishment of fetal neuronal activity begins. The ensuing appearance of synapses within the cortical plate between 19 and 23 weeks gestation was associated with the period of growth of axons into the cortical plate and with the proliferation of dendrites. Apical dendrites, which appear by the 18th week, develop primitive spine-like processes by 22 weeks (Purpura 1964). Synapses are still immature at birth (Herschkowitz 1988).

The auditory system of the neonate exhibits relatively more maturity in peripheral structures than do the midbrain and cortical structures (Hecox 1975). The auditory cortex, which is in an immature state at birth, is not of importance in the elicitation of a startle or attention response to auditory stimulation (Graham et al. 1978, Heffner 1978). However, it appears to be essential in more complex functions such as the habituation of response or the localisation of sound (Hecox 1975, Brackbill 1971, Griffin 1963, Glaser and Griffin 1962, Heffner 1978). While lesions of the lateral tegmentum do not interfere with the startle response in sensory processing, this area has been shown to be

involved in the processes of inhibition and habituation of response (Leitner et al. 1979, Leitner et al. 1981).

Latency of auditory evoked responses is shown to decrease with age, ranging from 40 dB between 28 and 34 weeks gestational age to below 20 dB in term infants (Lary et al. 1985). Hecox and Burkard (1982) conclude, from a review of the literature, that a variety of factors may be responsible for this decrease in latency: resolution of middle ear transduction abnormalities; maturation of the basal portions of the cochlea; increased synaptic efficiency; improved myelination; and superior synchrony of responses. A change in cochlear responsiveness during maturation is suggested by Starr et al. (1977) possibly to account for the differences in detecting cortical and brain stem potentials, in the light of the initial restriction of cochlear function to the lower frequencies, with extension of sensitivity to higher frequencies appearing with maturation. The decreasing acoustic thresholds coinciding with increasing age may be a function of problems of measurement. It is indicated that maturation of auditory function proceeds at the same rate in both the extrauterine and intrauterine environments.

A study of neonatal evoked response audiometry by Taguchi et al. (1969) determined significant air-bone differences in hearing thresholds up to 2 days after birth, indicating a conductive hearing impairment during this period, which was attributed possibly to mesenchymal tissue in the tympanic cavity. The embryonic mesenchymal tissue which exists in the neonatal middle ear, not becoming pneumatized until several days after birth, causes an increased stiffness of the tympanic membrane (Holt and McIntosh, 1961, Barnett and Einhorn 1972, Nelson 1959, Keith 1975). The acoustic reflex of the neonate is shown to be fully developed and functional at birth, with reflex threshold levels being similar to those of adults (Weatherby and Bennett 1980, Bennett and Weatherby 1982, Sprague et al. 1985). However, this does not provide a measure of hearing ability as the acoustic reflex can be elicited in a subject with profound hearing loss.

Webster and Webster (1977) determined profound central neural changes in the brain stem auditory nuclei as a result of sound deprivation. The globular cell group of the ventral cochlear nucleus and the medial nucleus of the trapezoid body were affected. It was hypothesised that there may be a critical developmental period in which proper, meaningful sound must be received for the central auditory system to mature normally. It has further been postulated that the perinatal period is one of maximal brain growth and that stimulation is required to develop neural and behavioural patterns (Reisen 1961). A deprived period may result in an omission in the normal infant's pattern of sequential development, which may be permanent (Rothchild 1966).

2.4 DISCUSSION

In endeavouring to determine the onset of hearing function in the human fetus, one encounters the problem of defining the exact point at which the structures involved became functional. If different aspects of hearing develop in varying stages, as suggested by Rubel (1985), then it is clear that no single event triggers function. While some development of cochlear microscopic structures and myelination continues postnatally (Parmalee 1981), there is sufficient embryologic evidence to suggest that some hearing function begins months before birth. The structural maturity of the cochlea, sensory end-organs and basilar response attained by the 24th week, the linking of the eighth cranial nerve and the spiral ganglion with the sensory end organs, the activity of the eighth cranial nerve and the detection of cortical and auditory brain stem potentials in the preterm neonate together indicate the probability of some hearing function by about 25 weeks gestational age (Anson and Donaldson 1973, Marty and Thomas 1963, Starr et al. 1977).

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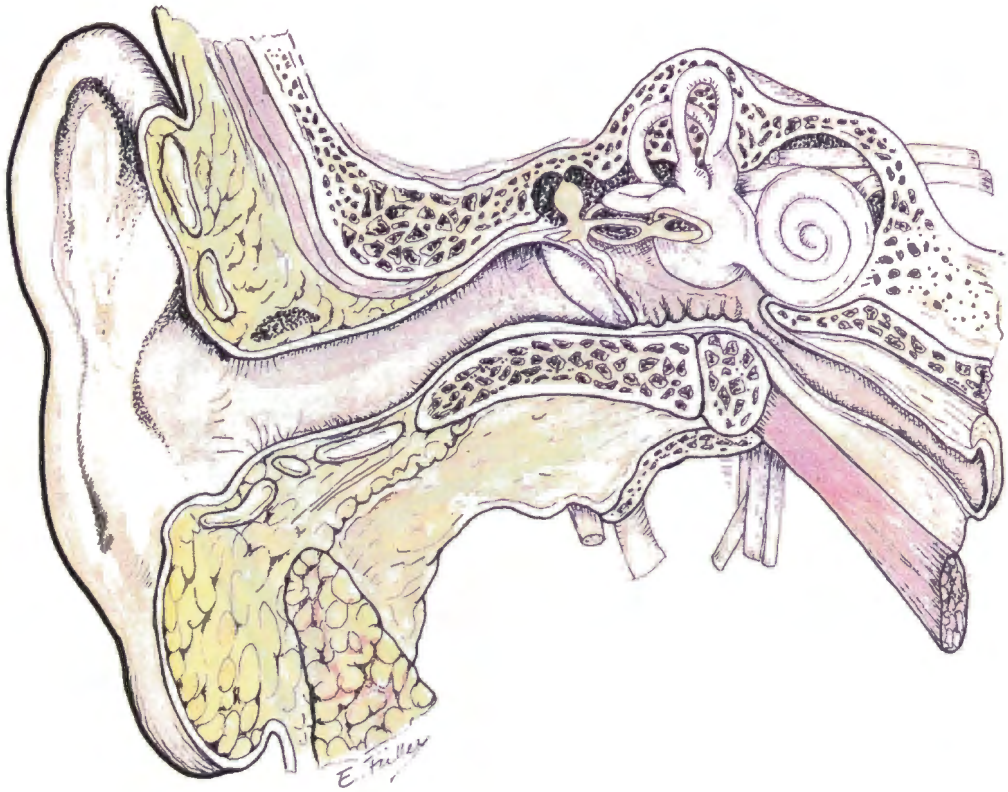


FIG 2.1. The ear

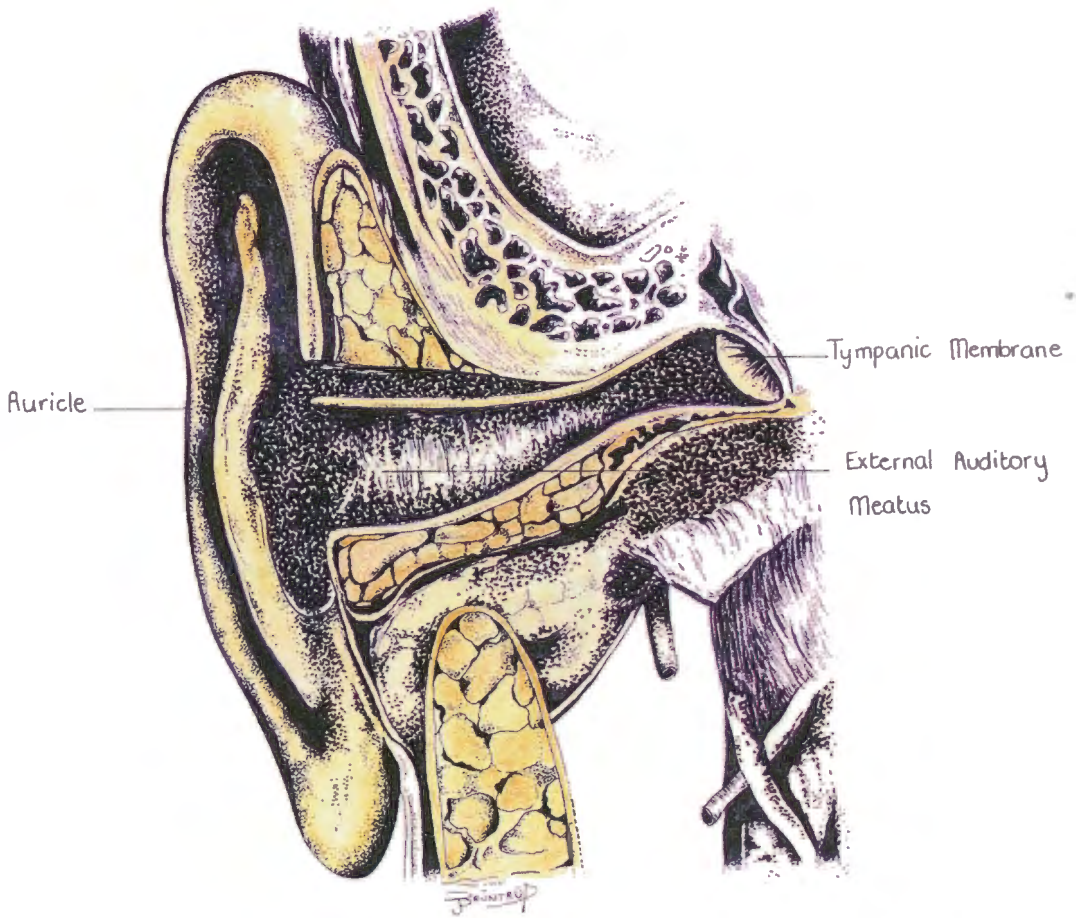


FIG 2.2. *The external ear*

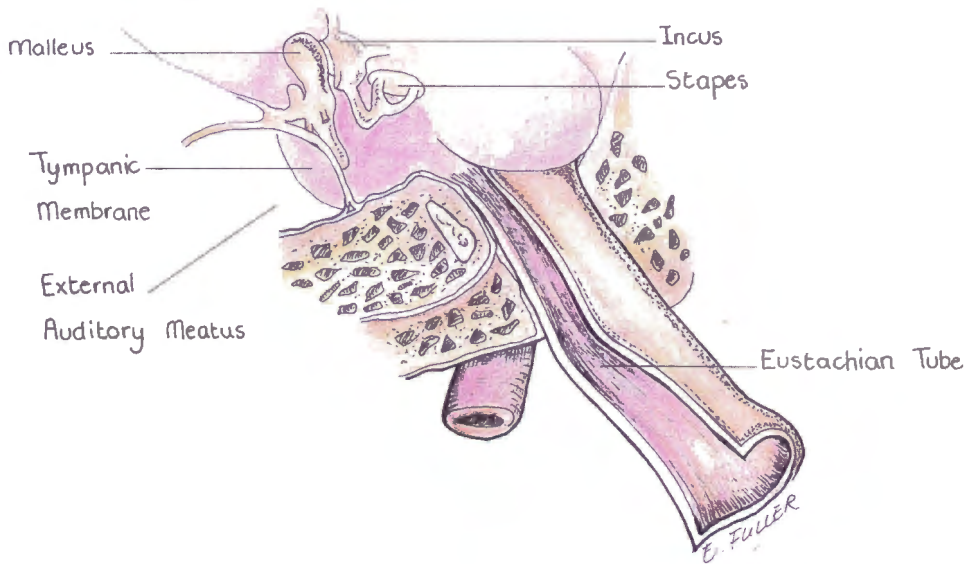


FIG 2.3. The middle ear

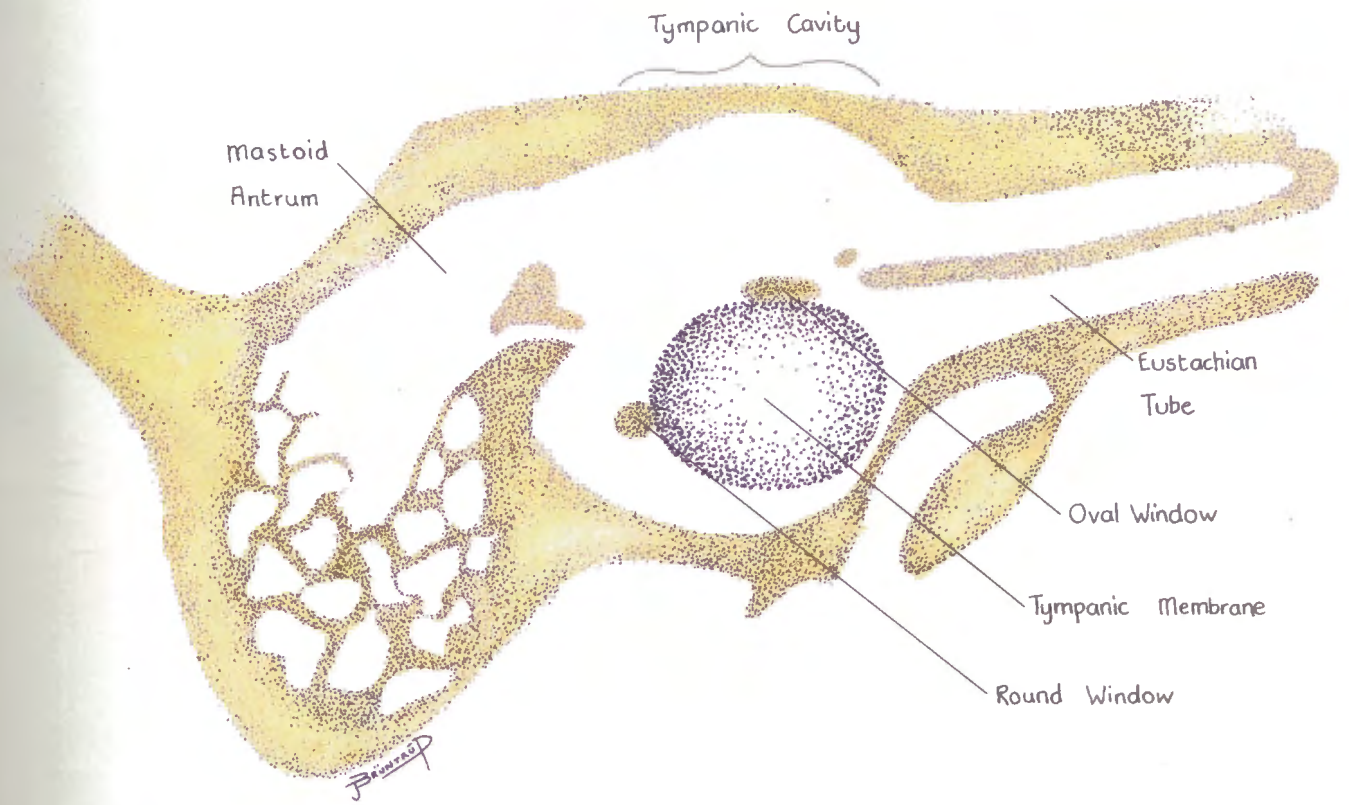


FIG 2.4. Schematic representation of the middle ear, lateral view.

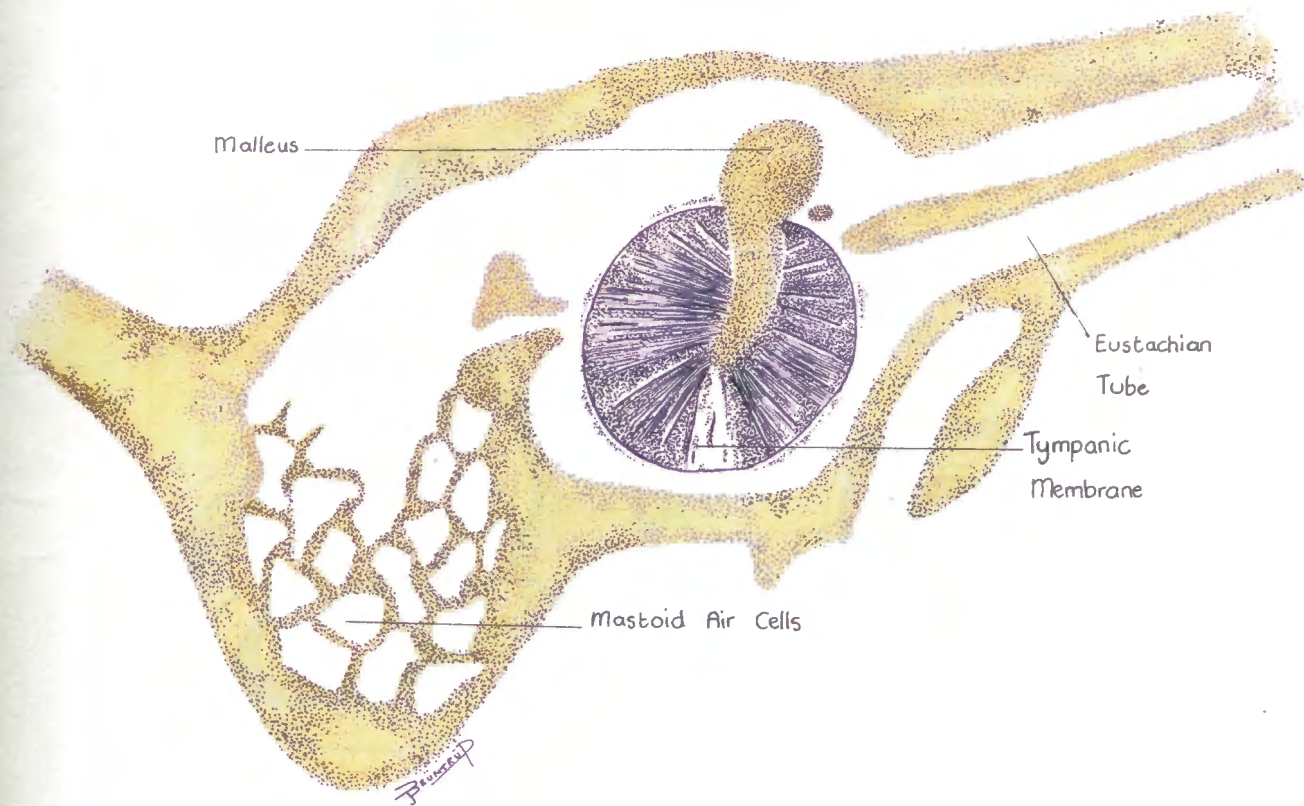


FIG 2.5. *Schematic representation of the lateral wall of the middle ear, viewed from the medial aspect.*

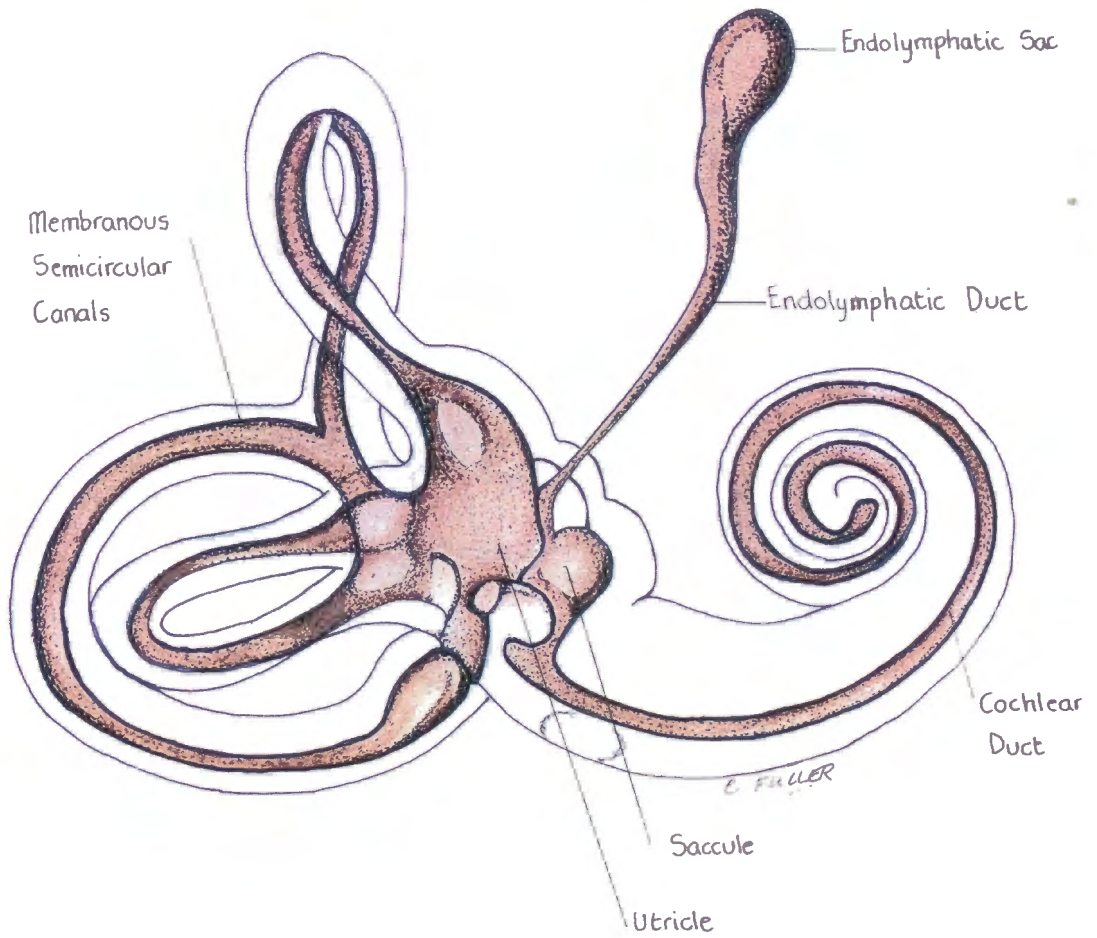


FIG 2.6. *The membranous labyrinth encased in the bony labyrinth.*

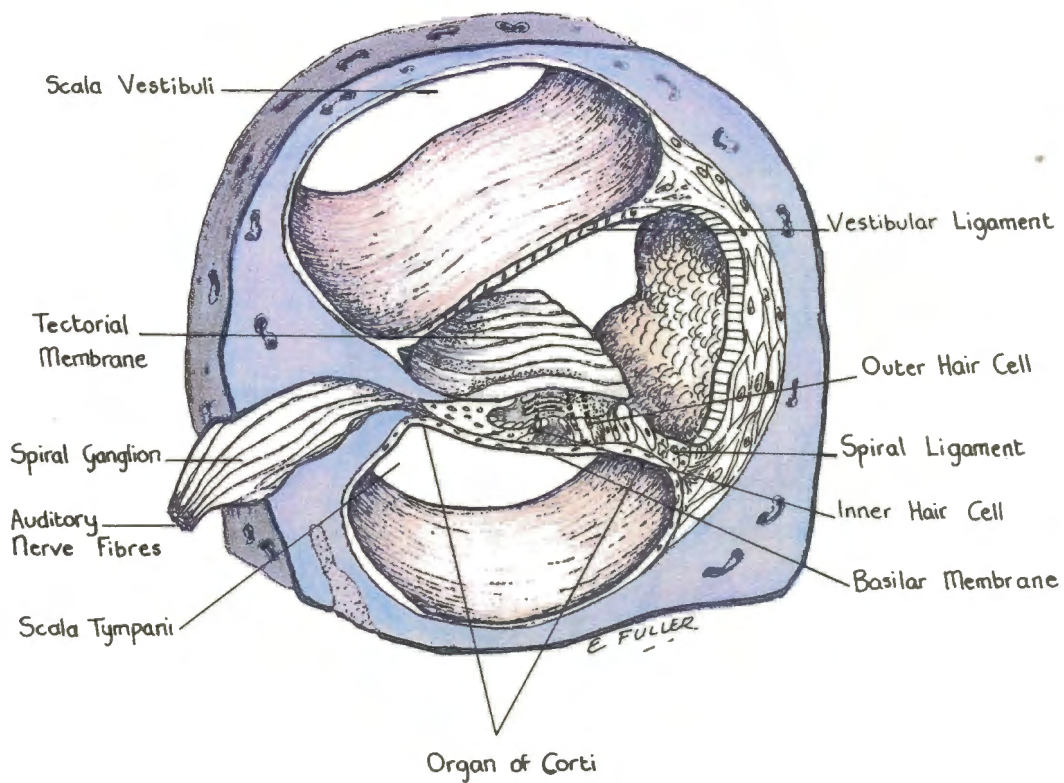


FIG 2.7. Cross section of the cochlea

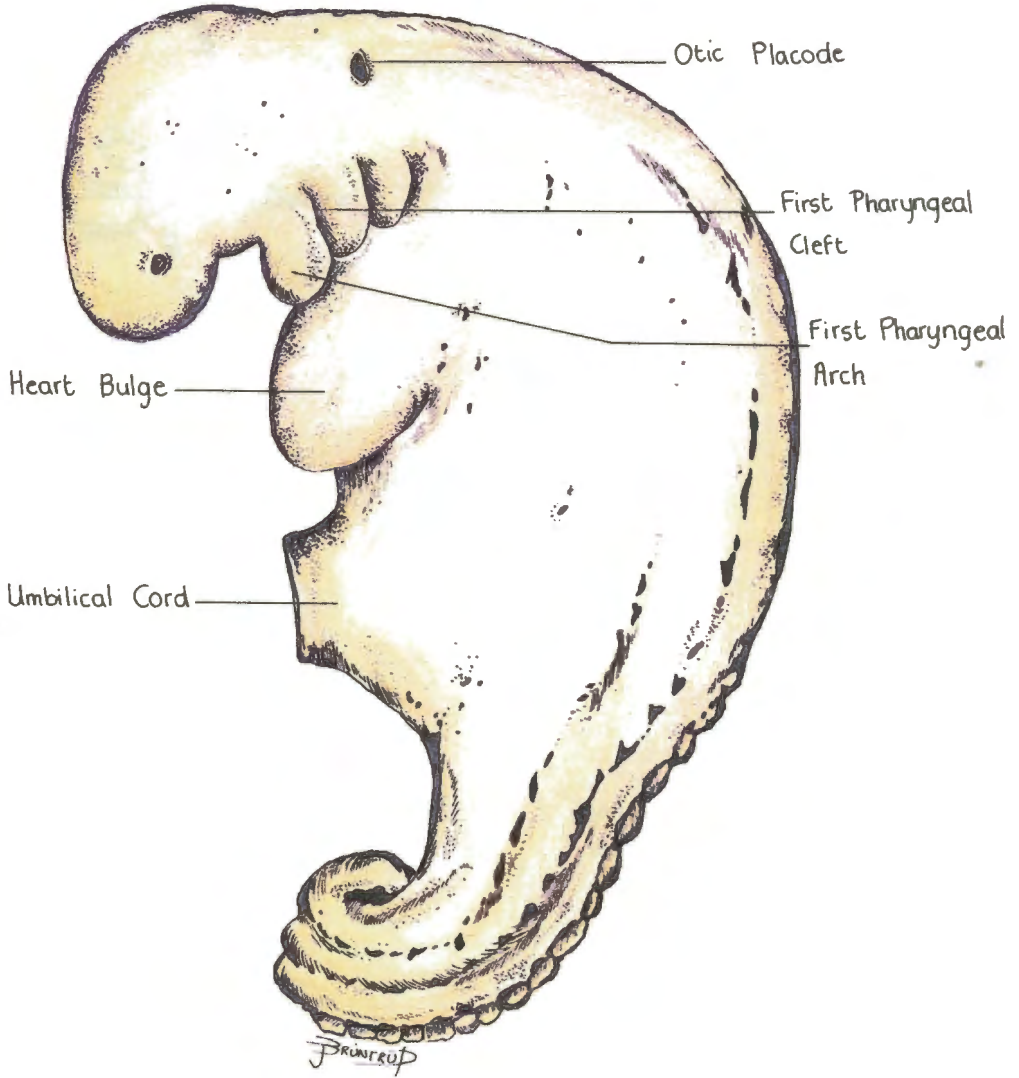
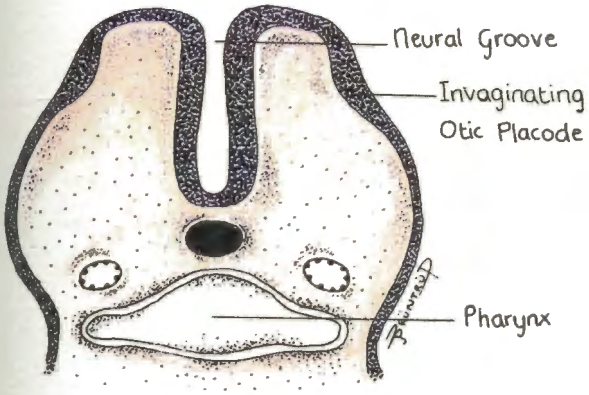
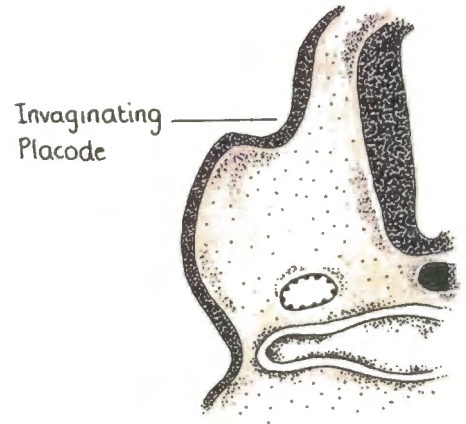


FIG 2.8. *The 28-day old embryo*



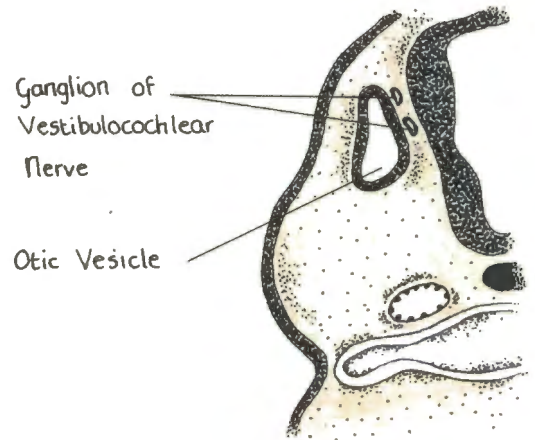
A. 22 DAYS



B. 24 DAYS



C. 27 DAYS



D. 32 DAYS

FIG 2.9 A-D. Schematic representation of the developing inner ear from 22 - 32 days.

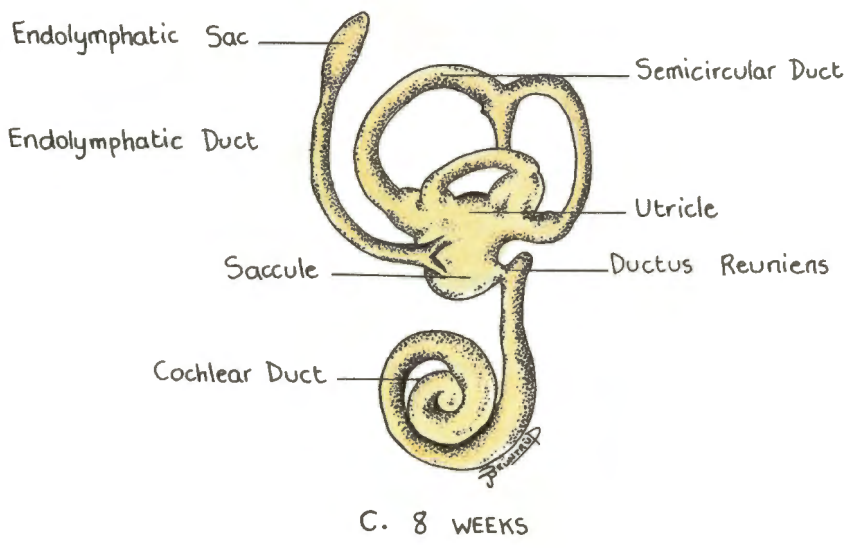
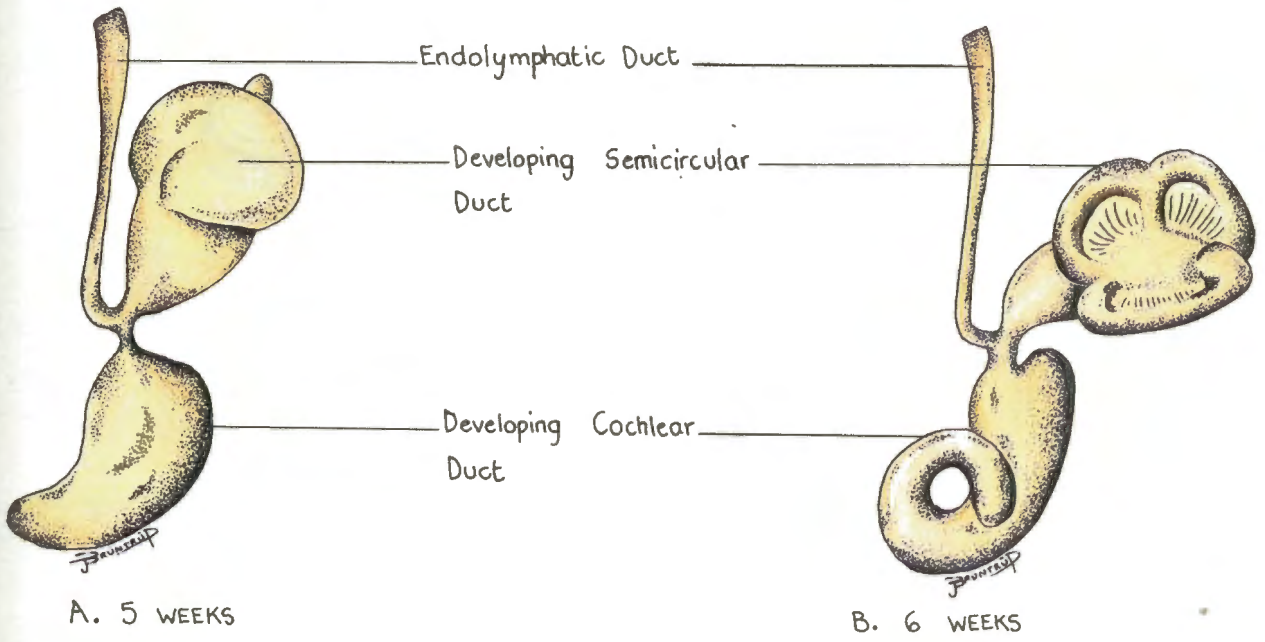


FIG 2.11 A-C. Schematic representation of the developing semicircular ducts and cochlear duct from 5 to 8 weeks.

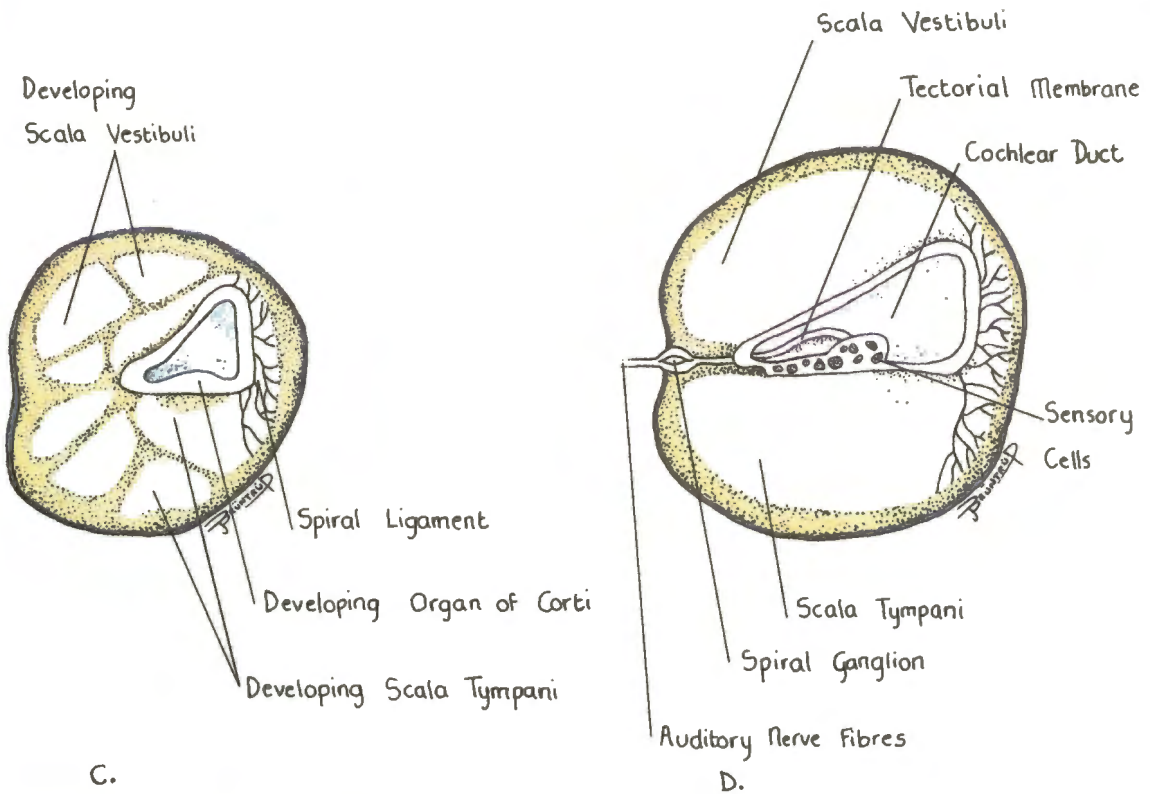
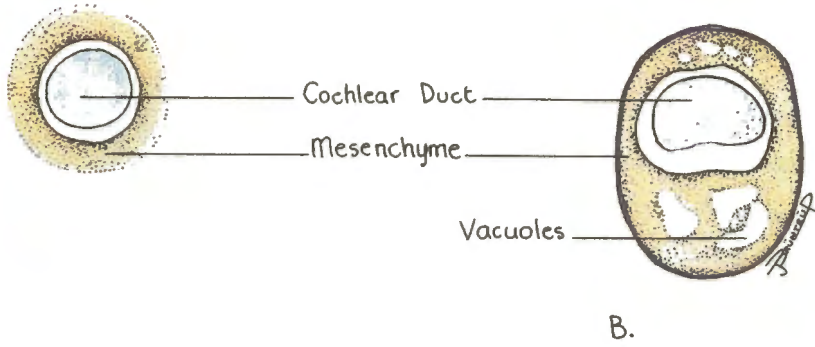
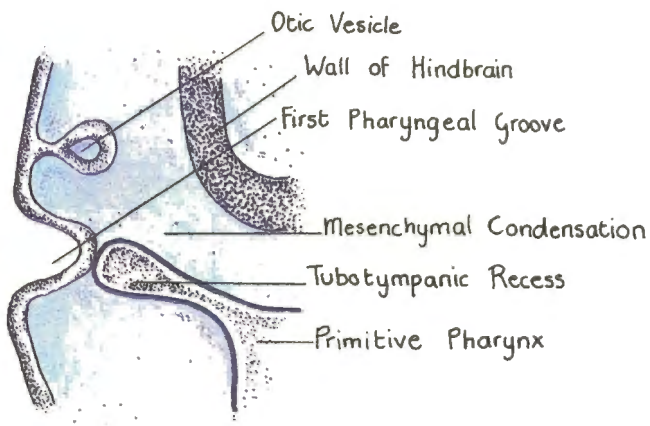
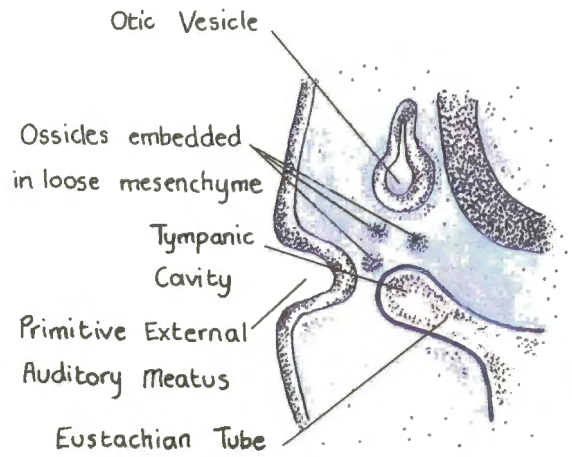


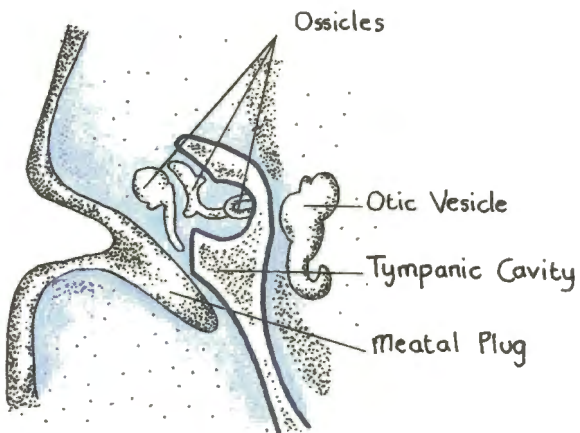
FIG 2.12 A-D. Schematic representation of the developing perilymphatic spaces and organ of Corti from 8 to 12 weeks.



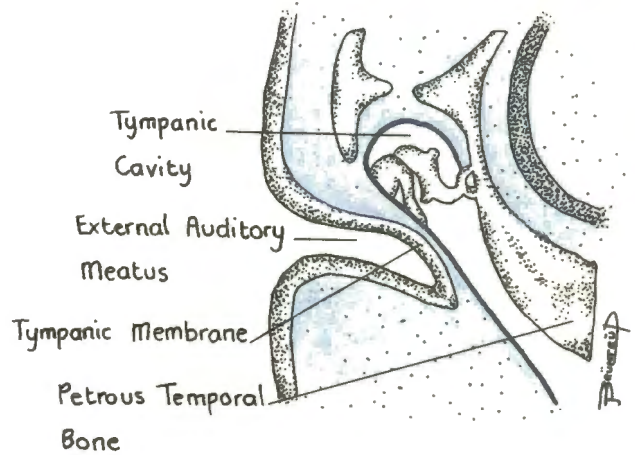
A.



B.

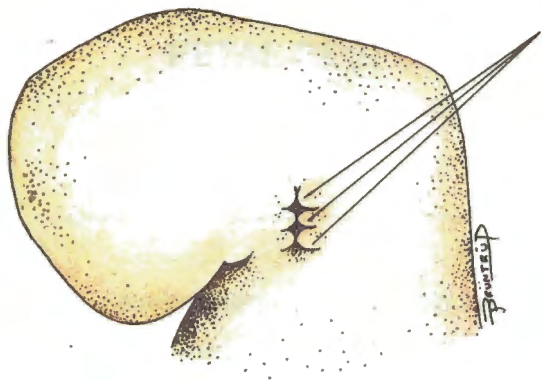


C.



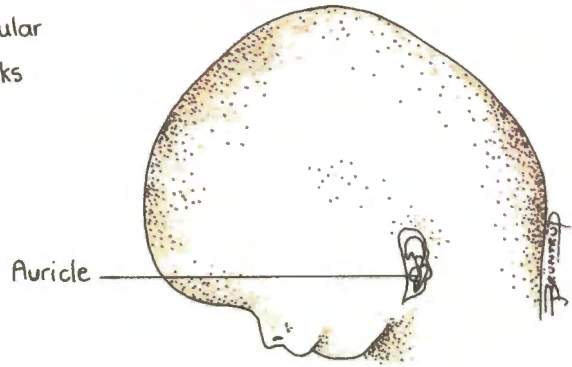
D.

FIG 2.13 A-D. Schematic representation of the developing middle ear and external auditory meatus from 5 weeks to 7 months.



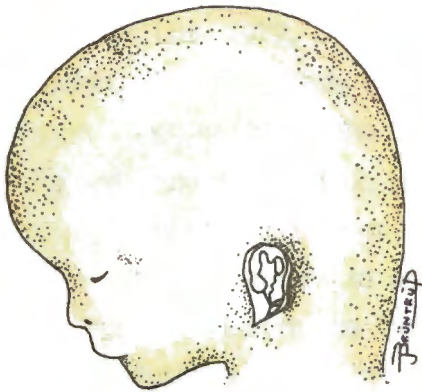
Auricular
Hillocks

A. 6 WEEKS

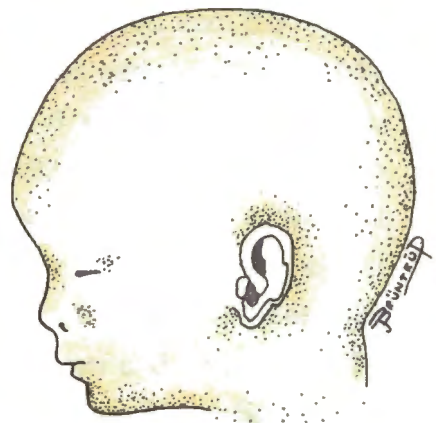


Auricle

B. 8 WEEKS



C. 10 WEEKS



D. 32 WEEKS

FIG 2.14 A-D. Schematic representation of the developing auricle.

FETAL RESPONSE TO ACOUSTIC STIMULATION

The development of ultrasonic imaging has led to a modification in the concept of the human fetus, previously pronounced to be in a permanent stupor/coma, with almost certainly no developed sense of hearing (Preyer 1885) but now seen as perceptive and responsive, displaying individual patterns of behaviour (Goodlin 1979). Intrauterine activities include respiratory movements, sucking of the thumb/fingers, clasping hands, eye blinks, rapid and slow eye movements, complex facial movements, smiling, crying after painful procedures, urinating, increased swallowing of sweet amniotic fluid achieved by the injection of saccharin into the amniotic fluid and decreased swallowing of bitter amniotic fluid achieved by the injection of lipiodol (Timor-Tritsch et al. 1986, Ianniruberto and Tajani 1981, Bots et al. 1981, Valman and Pearson 1980, Goodlin 1979, Anand and Hickey 1987, De Snoo 1937, Liley 1972, Thoman 1980). Fetal reflexes are observed from 5.5 weeks gestation, electrical activity of the brain has been reported as early as 43 days and smooth movements of the body are observed from 6 weeks (Hooker 1952, Fitzgerald and Windle 1942, Borkowski and Bernstine 1955, Okamoto and Kirikae 1951, Ianniruberto and Tajani 1981). The fetus responds - by means of movement and/or cardiac change - to bright light in the second trimester of pregnancy, to tactile stimulation from the 7th week, to temperature change from 18 weeks (by means of flushing cold saline through an intrauterine catheter) and to the pain of a needle prick during amniocentesis from 26 weeks (Brazelton 1981, Scrimgeour 1976, Hooker 1952, Goodlin 1979, Tanaka and Arayama 1969).

Maternal perception of changes in fetal movement patterns when exposed to certain sounds, such as the slamming of a door or a music concert, has led to intensive

studies on fetal response to acoustic stimulation (AS). From as early as 1925, investigations into the subject were made by Peiper (1925). He demonstrated that fetal movement occurred when a shrill, loud hooter was sounded. Since then, detection of fetal response to AS has been repeatedly confirmed (Bernard and Sontag 1947, Dwornicka et al. 1964, Jensen (1984a). Functional maturation of the fetal auditory system (shown to be structurally mature by the 25th week gestation) is indicated by the study of autonomic nervous system indices, behavioural response and average evoked auditory response to sound (3.1). The occurrence and magnitude of response to AS is influenced by the gestational age of the fetus (3.2), the characteristics of the sound sources used (3.3) and the behavioural state of the fetus at the time of stimulus presentation (3.4).

3.1 TYPES OF RESPONSE

A wide variety of human fetal responses to AS has been determined in published research, including measurements of central nervous system indices (3.1.1), autonomic nervous system indices (3.1.2), behavioural response (3.1.3) and electroencephalographic response (3.1.4). These are shown to be independent of maternal response. In order to confirm that fetal heart rate (FHR) changes were not caused by maternal reaction to the auditory stimulus, Grimwade et al. (1971) observed maternal heart rate which was found to remain unaltered during testing. However, significant FHR changes were determined immediately after AS. Similar observations of unaltered maternal blood pressure and heart rate (and significant changes in FHR) following vibroacoustic stimulation (VS), were made by Gagnon et al. (1987b). In other studies, the mother wore headphones which enabled the stimulus to be masked (Lecanuet et al. 1986, Querleu et al. 1985). Some emotional and psychophysiological effects of sounds on the fetus have been indicated but not clearly elucidated (3.1.5).

Besides the influences of gestational age, behavioural state and the type of stimulus on fetal response to AS, it is pointed out that medication also may affect response. For example, beta-adrenergic blocking agents are occasionally administered in the treatment of pregnancy-induced hypertension, with one of the effects being a decrease in heart rate. A dose of

80 mg of propranolol, administered orally to the mother, was shown by Jensen (1984b) to cause significant depression of FHR response to AS, indicating its immediate effect on the fetal nervous system.

Theories regarding the transference to the fetus of maternal emotional responses to sound are mentioned (3.1.5). Some contradiction may be implied by the effects of music on the mother mentioned in these studies and the observation of no maternal responses to AS or VS in other studies. This may be explained by the types of responses observed. Some studies involve a fetal startle response to stimuli which is not observed in the adult. The process of habituation (where response diminishes with repetition of a stimulus) is essential for survival, and hence the lack of startle responses in the adult to many familiar sounds. However, other responses (such as a change of heart rate over a period of time) may be determined in adults (3.1.5).

3.1.1 Central nervous system indices

Birnholz and Benacerraf (1983) determined auropalpebral (APR, blink-startle) responses to VS. The APRs were easily determined because they were immediate, bilateral and forceful. They were frequently associated with contraction of the cheek and frontalis muscles. Other components of the startle response, such as head aversion, arm movement and leg extension, were also evident with the initial pulse. There was an increase in yawning activity after the stimulus sequence was concluded. Kuhlman et al. (1988) recorded behavioural startle responses consisting of head, hand and facial movements, which seldom occur together spontaneously. The components included head turning, mouth opening, tongue protrusion, cheek motion, hand-to-head movement and eyelid blinking. The data indicated a consistent startle response to VS in the normal fetus from 28 weeks.

3.1.2 Autonomic nervous system indices

By means of cardiotocography, tracings of the fetal heart rate can be obtained for analysis. Criteria for interpretation include baseline rates and short and long term variability. While FHR tracings can be visually or numerically analysed (Visser et al. 1981), comprehensive FHR monitoring can also be achieved by means of a programmed microcomputer (Devoe and Searle 1986, Divon et al. 1984). Fetal heart rate acceleration in response to AS is considered a normal response, indicative of fetal well-being (Romero et al. 1988). It has been described as a "startle" response, thus providing indication of the integrity of the autonomic nervous pathways (Divon et al. 1985).

One criterion for positive response to pure tone AS in the study by Marin et al. (1987) was a FHR acceleration of at least 15 beats per minute (b/m) occurring within 15 seconds (sec) of the stimulus and lasting at least 15 sec. Trudinger and Boylan (1980) observed that the normal fetus exhibits an acceleration of 15 b/m, sustained for at least 2 minutes (min) after presentation of a pure tone stimulus. Read and Miller (1977), measuring FHR accelerations of at least 15b/m, observed positive response to pure tone AS in normal fetuses which were later delivered healthy. Jensen (1984a) applied a pure tone stimulus only when the FHR was relatively stable, and measured the maximum FHR increase within 10 sec. He observed positive response to pure tone stimuli in normal fetuses.

Ohel et al. (1986a) and Ohel et al. (1986b) observed that after VS, the baseline FHR and the number of accelerations was significantly increased. Three responses were observed: acceleration of at least 15 b/m lasting 15 seconds; tachycardia of at least 15 b/m occurring longer than 2 minutes; and a triphasic response (FHR acceleration interrupted by deceleration). The latter was more common in cases of abnormal FHR tracings. Davey et al. (1984) considered a test reactive if a plateau elevation of basal rate of at least 15 b/m occurred over a period of not less than 5 min of the 10-min AS test. It has been determined that VS results in a significant increase in mean duration of

FHR accelerations, the mean amplitude of FHR accelerations and the total time spent in accelerations for up to 15 min (Gagnon et al. 1986b). A study by Gagnon et al. (1987b) determined an immediate increase in fetal basal heart rate persisting for 1 hour after the stimulus, as well as an increase in the total time during which accelerations occurred for the first 20 min after the stimulus. Responses of term fetuses to VS were studied by Devoe et al. (1989), indicating transient alterations in FHR baseline and variation, mostly occurring within 15 min. An increase in the baseline FHR after VS was observed by Wladimiroff and Cheung (1989) in healthy fetuses. Auscultation of the FHR, recorded on a specifically-designed graph, has provided similar results to those obtained by means of cardiotocography (Paine et al. 1988). In a study of twins, Sherer et al. (1991b) determined that nonsynchronous, spontaneous FHR accelerations occur naturally and that VS causes immediate, synchronous FHR accelerations.

A decrease in fetal breathing activity during the first 15 min after VS was determined by Devoe et al. (1989). A significant decrease in the incidence of fetal breathing movements in the hour after VS when compared with control values was determined by Gagnon et al. (1986a) and Gagnon et al. (1987c). Sherer et al. (1991a) observed fetal panting (rapid movements of the chest wall and diaphragm) which lasted for 40 min after VS.

3.1.3 Behavioural response

The testing of behavioural response was suggested by Leader et al. (1982a) to provide more information than that obtained in a test of the autonomic nervous system, as both sensory and motor responses are involved, requiring a higher degree of neuronal involvement. Detailed observation of fetal behaviour and movements is made possible by means of ultrasonic imaging.

A study of maternal perception of fetal movement determined an 87% response to VS on 613 occasions in 259 high-risk pregnancies

(Westgren et al. 1987). Fetal startle response to AS involving immediate trunk or limb movement was observed by Leader et al. (1982a). Maternally-perceived and observer-perceived fetal movement was determined by Thomas et al. (1989) to be more consistently elicited in response to VS in term fetuses (96.7% and 90% respectively) than in preterm fetuses (87% and 87%). The use of ultrasound facilitated the observation of fetal movement in a study by Visser et al. (1989). It was concluded that VS induces excessive fetal movements. A significant increase in fetal movements after VS was determined by Ohel et al. (1986a). Gagnon et al. (1987c) observed a significant increase in the incidence of gross fetal body movements from the hour before, to the hour after the stimulus application. Comparetti (1980), observed fetuses "turning towards" a strong auditory stimulus, while Brazelton (1981) determined that fetuses are startled by a loud sound and "move towards" a soft, humming noise. Sadovsky et al. (1987) determined that 75% of fetal movements occur non-simultaneously in twin fetuses, while AS was shown to elicit vigorous, simultaneous fetal movements in 9 sets of twins. The application of a 2000 Hz stimulus at 100 dB applied against the maternal abdomen was reported by Gelman et al. (1982) to result in a significant increase in the number of fetal movements, persisting for 30 minutes after the stimulus.

The fetus alternates between four different states defined by Nijhuis et al. (1982) as 1F, 2F, 3F and 4F (corresponding approximately to deep sleep, active sleep, quiet awake and active awake states, respectively). Similar classifications (based on FHR patterns, eye movements, gross body movements, small movements, and breathing movements) were made by Martin (1981). Alteration from a state of low fetal activity to one of high fetal activity, as a result of VS, was observed by Ohel et al. (1986a). This theory is supported by the results of another study determining consistent occurrence of fetal movement and altered baseline FHR after VS (Smith et al. 1986). Data obtained by Gagnon et al. (1986a) demonstrated that fetal breathing movements and gross body movements were significantly altered for up to 1 hour after a 5-sec vibratory acoustic stimulus. As a result, it was hypothesized that the changes reflected a switch from sleep to wakefulness. In a later

study, Gagnon et al. (1987b) suggested that the results were compatible with the theory that a change in state from one of sleep to one of wakefulness had occurred as a result of the VS. A change in state after VS (requiring significant coincident differences in FHR variation, body movement incidence, breathing activity and FHR baseline) was not observed in tests by Devoe et al. (1989), but it was suggested that disorganisation of behavioural state may occur. Devoe et al. (1990) consider the fetal behavioural state rather to become 'reorganised'. Fetuses in state 1F consistently converted to state 4F; and fetuses in state 4F maintained their behaviour patterns. However, the variability in poststimulus behaviour for fetuses not in state 1F or 4F, caused them to deduce that the mechanism for FHR accelerative responses to VS is not simply caused by state conversion.

An increase of fetal activity has been shown to persist for 30 minutes after AS (Gelman et al. 1982). Patterns of gross fetal body movements, as well as breathing movements, were significantly altered for up to 1 hour after VS (Gagnon et al. 1986a). It has been indicated that vibroacoustic stimulation of the fetus induces excessive fetal movements, a prolonged tachycardia, non-physiological state changes and a disorganisation and change in the distribution of fetal behavioural states (Visser et al. 1989).

3.1.4 Electroencephalographic response

Electroencephalographic response of the fetus is discernible by placing electrodes on the maternal abdomen, or by insertion of a vaginal speculum containing exposed electrodes, which are placed on or near the fetal scalp during labour. Cortical potentials and auditory brain stem potentials have been detected in the preterm neonate of 25 weeks gestational age (Starr et al. 1977), providing some indication of functional maturity of the fetal auditory structure at this stage. Electroencephalograms of the fetus (FEEG) from as young as 43 days gestational age have long been determined (Lindsley 1942, Okamoto and Kirikae 1951, Bernstine et al. 1955, Borkowski and Bernstine 1955).

Metallic skin electrodes placed on the fetal scalp at the occiput in a study by Rosen and Satran (1965) determined electrical activity during labour similar to that seen in the alert newborn infant. A gradual increase in cortical voltage immediately after delivery was also determined and, within five minutes, the EEG tracing was the same as that of the neonate several hours after birth. Using a transducer device introduced into the uterine cavity in the vicinity of the fetal ear, Barden et al. (1968) generated an acoustic signal, simultaneously recording FEEG activity by means of skin-clip electrodes attached to the presenting vertex. A clear and consistent auditory-evoked electroencephalographic response was found in one of 6 subjects, suggesting that more discernible responses may be detected with further study. The study by Sakabe et al. (1969) determined average evoked responses, associated with a tone burst at 1000 Hz, in 6 fetuses from 32 to 38 weeks gestation. These corresponded with the components of the slow cortical potential which is elicited to auditory stimulation in young children.

3.1.5 Emotional and psychophysiological response

The emotional influence of music on humans has been widely documented (Noy 1967, Pignatiello et al. 1986, Stratton and Zalanowski 1988). The emotional response of the fetus to music is largely unexplored. Certain components of music might be inherently agitating or restful, piercing or gentle, etc. (Hevner 1936, Scherer and Oshinsky 1977). However, a large degree of mood, image and emotional association of music components are shown to be the product of conditioning (Lundin 1967, Zalanowski and Stratton 1990). Besides the power of the music itself to emotionally and psychologically influence humans, perception of music is affected by external influences such as the past or present physical and psychological context, which influence one's attitude towards it.

The deleterious effects of noxious sounds on the developing fetus have been suggested in several studies. Chronic noise exposure has been associated with reduced levels of human placental lactogen in the

serum of expectant mothers and reduced prenatal growth (Ando and Hattori 1977, Schell 1981).

Many studies on fetal response to AS have determined that the fetal response is independent of maternal response. Whereas FHR response to AS was determined, changes in maternal HR were not evident (Grimwade et al. 1971, Gagnon et al. 1987b). However, the possibility exists that if the mother responds physiologically or emotionally to an acoustic stimulus, that the fetus may be influenced by that maternal response.

The works of Ferreira (1965), Ferreira (1969) and Verny (1981) also propose the theory that the fetus is affected by maternal emotional state. Fetal activity has been shown to increase with maternal stress (Valman and Pearson 1980). Hormones produced in the event of maternal fear, such as epinephrine have been shown to cause increased uterine activity (Kelly 1962). Sudden extreme maternal fright has been associated with fetal death (Goodlin 1979). The incidence of schizophrenia and criminal activity was shown to be greater in individuals who were born after the death of their fathers than those whose fathers died during the first year of life (Huttenen and Niskanen 1978). Davids and De Vault (1962) demonstrated that maternal anxiety during pregnancy is associated with childbirth abnormalities and with adjustment levels at 8 months of age, as revealed on psychometric examination. No correlation was established between intense but brief maternal stress and infant health in a study by Stott (1973). However, continuing tensions, incapable of resolution and likely to erupt at any time (such as marital discord), were closely associated with neurological dysfunction, developmental lag and behaviour disturbance.

Evidence of how the fetus is affected by maternal emotional response to music is scant. Observing fetuses from 34 weeks gestation, Zimmer et al. (1982) played music to the mother only, using headphones. Comparing a control period (no music stimulation) with two periods of

either classical or pop music, an apparent influence on the fetus was observed. During 25 minutes of a period in which music was played, the fetus displayed decreased breathing movements and increased body movements. The trend was more significant during the period of music which the mother preferred.

3.2 SOUND SOURCES FOR FETAL ACOUSTIC STIMULATION

Human fetal response is shown to vary as a function of stimulus intensity. High-pass filtered (800 Hz) pink noise was shown in two studies to elicit greater response ratios when presented at 110 dB than at 105 dB (Kisilevsky et al. 1989, Lecanuet et al. 1986). The lowest intensity required to reliably elicit a response was found to be 105 dB (Kisilevsky et al. 1989). Increased magnitude of cardiac acceleration has been associated with increased pure tone stimulus intensity (Jensen and Flottorp 1982).

The acoustic stimuli which have been successfully employed in obtaining positive fetal response vary, but usually fall into the categories of vibroacoustic stimuli, acoustic stimuli, high-pass or low-pass filtered noise and tones (sine wave or square wave). A few published tests involve the use of music stimuli. Clinical acoustic stimulation tests (ASTs), intended for the assessment of fetal well-being, generally utilise a vibratory acoustic sound source (Romero et al. 1988).

3.2.1 Vibroacoustic stimuli

Vibroacoustic sound sources are shown to consistently elicit response in the normal third trimester fetus, in the form of APR (Birnholtz and Benacerraf 1983), FHR accelerations, increase in basal FHR and gross fetal body movements (Ohel et al. 1986a, Gagnon et al. 1986a, Gagnon et al. 1986b, Gagnon et al. 1987b, Devoe et al. 1990) and change in fetal breathing patterns (Gagnon et al. 1986a, Gagnon et al. 1987c, Devoe et al. 1989, Sherer et al. 1991a).

These vibroacoustic stimuli are generally produced by means of a hand-held, battery-powered artificial larynx. The intensity levels of the instruments are generally quoted as being about 103 dB in the air close to the probe surface (Visser et al. 1989) or 82 dB at 1 metre in the air (Smith et al. 1985, Smith et al. 1986, Druzin et al. 1989). However, this instrument is designed to propagate sound through tissue and fluid, therefore measurements in the air are of limited value. The fundamental frequency of the device is usually about 80 Hz, with harmonics ranging from 20 Hz to 9000 Hz. The stimulus is usually presented for 2 to 5 seconds. A standard Ronson electric toothbrush with sound intensity of 74 dB was used in tests by Leader et al. (1982a and 1984) and Davey et al. (1984). Westgren et al. (1987) presented a noise at 110 dB measured in air at 10 cm.

Much debate surrounds the question of whether fetal responses to VS are due to stimulation of the cochlea, or the cutaneous and vestibular organs, and/or proprioceptors in muscles and bones (Visser et al. 1989). A study of two anencephalic fetuses determined no response to VS, with the authors concluding that the fetal response to VS is mediated by auditory mechanisms (Ohel et al. 1986b). A test by Marin et al. (1987) determined no FHR response to pure tones of 750 Hz, 1000 Hz and 1500 Hz, in two anencephalic fetuses. However, Querleu et al. (1984) showed that VS elicited immediate FHR response in one anencephalic fetus, suggesting that this startle response is subcortical, rather than originating from the cerebral cortex. Gagnon et al. (1986b) suggested that the both the auditory and vibratory components on the vibroacoustic stimulator are important in the fetal response.

The response of the normal third trimester fetus to VS and AS is so consistent that the AST has become common in the measurement of fetal well-being (Romero et al. 1988). Jensen (1984c) found FHR response to AS significantly greater in fetuses in good condition, than in deprived ones. A good correlation has been established between FHR response to AS, a negative oxytocin stress test and a good fetal

outcome (Read and Miller 1977). Fetuses with positive response to AS were found by Serafini et al. (1984) to have comparably good outcomes with respect to all parameters investigated, whereas those lacking response had an increased risk of intrapartum fetal distress. The acoustic stimulation test (AST) was first suggested by Read and Miller (1977) and, since then, its success has led to comparisons with the non-stress test (NST), which is used widely for measuring fetal well-being. Both tests involve the monitoring of FHR by means of a cardiotocograph. In testing 116 at-risk patients, Trudinger and Boylan (1980) observed that the NST detected 39 % of compromised fetuses (with problems such as growth retardation, perinatal mortality and death), while 66 % were detected by the AST. Jensen (1984c) observed that the AST was more efficient in predicting pathological outcome than the NST.

While the NST is of widely accepted value in the surveillance of high-risk pregnancies, it has certain disadvantages not inherent in the AST. Smith et al. (1985) and Smith et al. (1986) showed the AST to be more efficient in two areas, namely reducing the prolonged testing time of NSTs and decreasing the number of non-reactive tests by almost 50 %. A study by Druzin et al. (1989) also determined a decrease in the number of nonreactive NSTs after vibroacoustic stimulation. A fetus in the 'deep sleep' state F1 (as defined by Nijhuis et al. 1982), may take as long as 40 minutes to demonstrate spontaneous reactivity (Serafini et al. 1984). However, it is not necessary to wait for the fetus to enter an active state in order to perform the AST. Davey et al. (1984) found that, with the number of equivocal tests significantly reduced, the need for repeated tests (as in the case of the NST) was decreased. It was concluded that the AST was more reliable than the standard NST. Fewer false positive results are indicated in the AST (Smith et al. 1986). It was suggested by Querleu et al. (1985) that the AST has a better discriminatory value in detecting the risk of neonatal distress than the NST.

3.2.2 Acoustic stimuli

While the assemblage of studies on the subject leaves no doubt as to the fetal response to AS (with no vibratory content), not all researchers have determined reliable response to sound. This may be attributed to the variety of parameters regarding the frequency, intensity and duration of the stimulus; the fetal state; and the use of normal or high-risk populations; etc. Sound attenuates during transmission into the uterus, as a function of frequency (Querleu et al. 1981), thus influencing intrauterine intensity levels of externally-presented stimuli. In order to exclude tangible vibration, Querleu et al. (1981) stated that the sound source must be above 800 Hz.

Fetal heart rate response to tones above 800 Hz, presented between 90 dB and 120 dB, was determined by Querleu and Renard (1981). Lecanuet et al. (1989) determined reliable fetal responses to broadband pink noise above 800 Hz when delivered at a minimum of 100 dB. Dwornicka et al. (1964) presented pure tones of 1000 Hz and 2000 Hz, determining an immediate acceleration of FHR in 29 out of 32 subjects. Positive FHR response to a 2000 Hz pure tone was observed by Read and Miller (1977) after 43 out of 58 presentations (in 39 subjects). The seven inconclusive results and the 8 nonreactive tests were mostly associated with positive oxytocin tests and/or fetal distress during labour. Serafini et al. (1984) determined 82.5% FHR response to a pulse of 1220 Hz, delivered at 126 dB, in 160 tests. Jensen & Flottorp (1982) presented a 2000 Hz signal at approximately 80 dB (related to the normal hearing threshold), delivered by means of a bone conductor placed in the anterior fornix of the vagina. A definite and easily measurable increase in FHR was determined in fetuses from 36 weeks gestation. Johansson et al. (1964) presented a pure tone of 3000 Hz at a sound pressure level of 110 dB. In 45 tests on 10 fetuses, there were 42 significant deviations in pulse rate. Trudinger and Boylan (1980) determined FHR response in all of the 12 normal fetuses tested to a relatively pure tone of 850 Hz for 10 sec. A study by Timor-Tritsch (1986) determined response of the fetus to a

square wave sound generated at 3000 Hz, at a sound pressure level of 115 dB, for a duration of 7 sec. The presentation of a high pass filtered (800 Hz) pink noise was determined to elicit greater cardiac response than leg movement response (Lecanuet et al. 1986). The 110 dB stimulus was shown to be reliable in causing a cardiac response.

A range of relatively pure tones from 20 Hz to 12000 Hz was determined to elicit FHR change in a study by Bernard and Sontag (1947). Querleu et al. (1985) determined fetal response to pure tones of 100 Hz, 1500 Hz and 2000 Hz, all presented at 110 dB for a duration of 5 sec. Gelman et al. (1982) presented stimuli of 500 Hz and 2000 Hz at 110 dB, each for a 1-minute period, which is longer than the customary 2 to 5-second stimuli used in many ASTs. A significant increase in fetal movements was determined after the application of the 2000 Hz stimulus, which was not evident after the 500 Hz stimulus. A significant alteration of FHR and fetal movement was determined in response to pure tones between 500 Hz and 1000 Hz in a study by Grimwade et al. (1971). A second test on fetuses during labour, included the presentation of the same range of pure tones by means of an intrauterine crystal earphone (which was specifically used to avoid the attenuation involved when high frequency sounds are presented externally). Sound stimuli from the intrauterine earphone were associated with FHR change in 31% of 54 presentations. Murphy and Smyth (1962) determined FHR response to pure tones. Reaction to the 500 Hz tone was elicited in 215 of 290 subjects and only 50 FHR accelerations were determined after exposure to the 4000 Hz tone. Both being presented at 100 dB, it may be assumed that the intrauterine sound pressure levels were lower for the 4000 Hz tone, due to varying attenuation levels. Tanaka and Arayama (1969) attempted to present pure tones at equal sound pressure levels by measuring the tones in the rectum. The 500 Hz, 1000 Hz and 2000 Hz tones were each determined to be approximately 90 dB at this position. Pulse rate and/or movement responses were determined in 124 out of the 134 subjects. In 8 cases, the response was limited to pulse rate, while 50 reacted only by

changes in movement. Of the 124 responsive fetuses, there was 100% response to the 500 Hz tone, 97% to the 1000 Hz tone and 86% to the 2000 Hz tone. Marin et al. (1987) determined responses to pure tones of 750 Hz, 1000 Hz and 1500 Hz, delivered at 120 dB, in 5 out of 8 normal fetuses.

Jensen (1984a) presented a sound stimulus of 2000 Hz at 80 dB, 75 dB and 70 dB. The proportion of non-responders to the 80 dB stimulus was significantly smaller than the proportion to 70 dB. Kisilevsky et al. (1989) determined that a pink noise, with frequencies below 800 Hz and above 20000 Hz eliminated, elicited more response at 105 dB than at 100 dB.

Suggestions for the use of acoustic stimulation tests in antenatal screening for deafness have been made by Tanaka and Arayama (1969), Birnholz and Benacerraf (1983) and Johansson et al. (1964), the early diagnosis of deafness being vital in the timeous implementation of intervention. The exclusion of vibratory components in sound sources and consideration of the possibility of fetal pathology would be essential. It is pointed out that such tests would have to indicate what process of the hearing function is being tested. For example, a startle response to AS can even be determined in the anencephalic fetus. The role of the cortex in acoustic processing can be observed by testing habituation to AS (Ohel et al. 1986b, Brackbill 1971). The wide variety of acoustic stimuli used in fetal surveillance and in determining maturation of fetal cortical sensory processing mechanisms, leads one to question whether the sound stimuli used are of optimal value. Criteria need to be established in the achievement of a reproducible stimulus in terms of intrauterine sound pressure levels etc. and in the elicitation of consistent response.

3.2.3 Music stimuli

Minimal studies of fetal response to music have been published. Olds (1985) tested whether FHR might be affected directly as a result of

maternal heart rate changes which occur when listening to music. He presented music to the mother only by means of headphones and found no change in fetal heart rate. However, playing music to the fetus only (by placing headphones on the mother's abdomen), FHR changes were always elicited. Olds determined the average FHR variability of 20 subjects to be 47 b/m without music, 52 b/m during a music excerpt by Gounod and 37 b/m during music by Chopin. In studies on twins, Olds (1985) observed that a piano music stimulus caused one twin to move away from the headphone. On presenting an orchestral piece, this twin returned and the other moved away from the headphone. In another test, twins showed simultaneous, but very different FHR changes. Olds (1985) was quoted as believing that the differing response of fetuses to the same piece of music (one twin's heart beating faster and the other's slower) might indicate personality traits. A test of fetal response to piano and choral music presented for five-minute periods determined increased incidence of FHR accelerations and movements at 38 weeks.

3.3 GESTATIONAL AGE AT WHICH FETAL RESPONSE TO ACOUSTIC STIMULATION OCCURS

The gestational age at which fetal response to AS occurs is a function of the type of stimulus used (spectral content, frequency, intensity, duration, etc). Different aspects of hearing develop in varying stages (Rubel 1985) and consideration should be taken of the individual differences in developmental rates between fetuses within the range of normality.

3.3.1 Vibroacoustic stimuli

The earliest age at which response of the normal fetus to VS has been observed, is about 22 weeks (Leader et al. 1982a). In the relevant research project, some fetuses did not respond until 30 weeks. Female fetuses responded, on average, 2 weeks earlier than males. By 27 - 28 weeks, 89 % of fetuses responded. Birnholz and Benacerraf (1983) conducted a serial

study from 12 to 32 weeks gestational age, finding some APR response to VS from 24 weeks and consistent response after 28 weeks. A delayed response (greater than 1.5 sec) in the form of arm or leg movements, without associated head movement or blink, was determined in 3 out of 24 subjects younger than 21 weeks gestation. The sharp, transitional appearance of auditory startle response at 25 weeks was stated to be an indicator of neuromotor maturity. It was concluded in this study that hearing is established by the start of the third trimester. While spontaneous eyelid movements were observed with increasing frequency after 26 weeks gestation, the APRs were easily determined because they were immediate, bilateral and forceful. Out of 680 fetuses, only 8 nonreactive tests were encountered, all of whom were either severely compromised, had structural anomalies, or were deaf.

The evaluation of FHR acceleration in response to VS, conducted by Gagnon et al. (1987a) from 26 weeks of gestational age, indicates the possible normal neurodevelopmental status of the fetus. An increasing percentage of fetal response to VS was observed to coincide with increasing gestational age. Results included 7% response at between 20 - 22 weeks; 22% response at 24 - 26 weeks; 89% response at 26 - 28 weeks; and 100% response at 30 - 32 weeks. A further test by Gagnon et al. (1987c) determined certain non-responses to VS at 26 to 30 weeks gestation, and a consistent FHR response after 30 weeks. The study also indicated differences in the HR and movement responses, dependent on gestational age. From 26 weeks to term, fetuses displayed FHR accelerations in response to VS. After 30 weeks gestation, the response included an increase in basal fetal heart rate and, after 33 weeks, a delayed response was observed where the increase in the number of FHR accelerations and gross fetal body movements lasted for up to 1 hour after AS. Term fetuses (from 36 to 40 weeks) also displayed more irregular breathing movements after AS. It was suggested that the AST may reflect a functional maturation of the central nervous system.

Kuhlman et al. (1988) recorded consistent fetal startle responses to VS from 28 weeks, with 47% response in the fetuses from 26 to 27 weeks. Thomas et al. (1989) determined that, during VS, FHR changes observed in term fetuses also occur in preterm fetuses from 26 weeks gestational age. These results were confirmed by Druzin et al. (1989) who determined that the incidence of

reactive nonstress tests after VS was significantly increased after 26 weeks gestation. Results included 7% reactive tests at 20 - 22 weeks; 22% at 24 - 26 weeks and 89% at 26 - 28 weeks.

3.3.2 Acoustic stimuli

The youngest reported response to acoustic stimulation was at 26 weeks gestation to a 3000 Hz tone at 110 dB (Wedenberg 1965). Jensen (1984a) determined that FHR accelerations, in response to a pure tone of 2000 Hz, increased with advancing maturity at 32 weeks, 35 weeks and 39 weeks but when corrected for differences in prestimulation FHR levels, this increase was described as being insignificant. A range of relatively pure tones from 20 to 12000 Hz was determined by Bernard and Sontag (1947) to elicit a response in fetuses from 30 weeks. Gelman et al. (1982) tested 60 fetuses during the third trimester of pregnancy, determining that a 2000 Hz stimulus elicited a significant increase in fetal movements. Trudinger and Boylan (1980) determined FHR response in all of 12 normal fetuses from 34 weeks gestation to a relatively pure tone of 850 Hz. Murphy and Smyth (1962) determined FHR response to pure tones presented at 100 dB, but did not specify the gestational age of the fetuses. However, it may be presumed that the youngest age was at least 30 weeks, this being the age specified in a detailed report on two subjects. Reaction to the 500 Hz tone was elicited in 215 of 290 subjects and only 50 FHR accelerations were determined after exposure to the 4000 Hz tone. The minimal response to the higher tone may be due to the greater attenuation levels of high frequency sounds, the 4000 Hz stimulus therefore being effectively of a lower sound pressure level than the 500 Hz tone. Tanaka and Arayama (1969) presented pure tones of 500 Hz, 1000 Hz and 2000 Hz to fetuses in the 6th to final month of pregnancy, with 124 out of the 134 displaying pulse rate and/or movement responses. No fetal responses to the stimuli were observed in the 6th month of pregnancy. Out of the 124 responsive fetuses, there was 100% response to the 500 Hz tone, 97% to the 1000 Hz tone and 86% to the 2000 Hz tone. Johansson et al. (1964) determined 42 significant deviations in pulse rate in 45 tests on fetuses between 33 and 38 weeks gestation, to a pure tone of 3000 Hz.

3.4 INFLUENCE OF FETAL BEHAVIOURAL STATES ON RESPONSE TO ACOUSTIC STIMULATION

Low-frequency VS appear to elicit fetal response regardless of state, while response to high frequency sound is dependent on state.

3.4.1 Vibroacoustic stimuli

It has been demonstrated that fetal response to VS occurs regardless of state (Leader et al. 1982a, Leader et al. 1984, Devoe et al. 1990).

3.4.2 Acoustic stimuli

Schmidt et al. (1985) tested fetuses in all four states with a pure tone of 2000 Hz at 120 dB. More frequent and consistent responses were observed during 'awake' states (3F and 4F) than in 'sleep' states (1F and 2F). It was almost impossible to elicit a response in state 1F. No evidence that the sound stimulation induced a change of state was determined. Timor-Tritsch (1986) delivered a square-wave sound generated at 3000 Hz and observed significantly higher probability of FHR accelerations during state 2F (79 %) than in state 1F (21 %). He concluded that it was difficult to wake a fetus in state 1F with an auditory stimulus of this nature. A high-pass filtered 800 Hz pink noise was presented by Lecanuet et al. (1986) to fetuses during low variability heart-rate episodes (corresponding with state 1F) and high variability episodes (state 2F). Response ratios were smaller during the former than during the latter.

3.5 DISCUSSION

The structural maturity of the hearing mechanism, the activity of the eighth cranial nerve and the detection of auditory evoked cortical and brain stem potentials in the premature neonate provide some indication of fetal hearing function by 25 weeks (Anson and Donaldson 1973, Gerber 1977, Starr et al. 1977). The large number of tests referred to in this chapter determining fetal

response to external acoustic and vibroacoustic stimulation provide further confirmation of fetal hearing function in the third trimester of pregnancy. The studies of fetal behavioural response, electroencephalic response and response of the central and autonomic nervous systems associated with acoustic stimulation, indicate fetal ability to perceive and respond to acoustic stimuli. What level of cognition is involved in this perception, is presently a matter of speculation. Whether sound and, specifically, music have the ability to affect the fetus emotionally and psychologically is not clear. Is emotional response to music an evolutionary process, beginning perhaps in the prenatal stage of development? The implications of the results referred to in the above mentioned studies may be far reaching as regards music education. While few studies pertain to the specific use of music, it may be inferred that the third-trimester fetus responds to sounds (including pure tones), then some form of musical influence may occur from the fetal stage of human life.

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FETAL RESPONSE TO ACOUSTIC STIMULATION DURING LABOUR AND DELIVERY

The principal participants in childbirth, both mother and the emerging fetus, have the potential for being affected by sound (Luz et al. 1980, Clark et al. 1981). The possibilities of the baby being directly influenced by sound or music during childbirth has received minimal investigation (4.1). However, a large number of publications refer to the use of music in labour and delivery, with specific reference to the mother (Livingston 1979, Clark et al. 1981, Hanser et al. 1983, Sammons 1984) (4.2). In view of studies indicating the influence of maternal emotions on the fetus, it is suggested that the psychological benefits for the mother, through the use of music, may indirectly benefit the fetus. Certainly any aid in hastening the progression of labour (achieved by relaxing the mother) would provide an obvious physical benefit for the baby.

4.1 FETAL RESPONSE TO ACOUSTIC STIMULATION DURING LABOUR AND DELIVERY

Luz et al. (1980) determined fetal heart rate and motor response during labour to an acoustic stimulus of 1500 Hz, presented at 125 dB. The response elicited in vigorous fetuses was observed to gradually diminish with the progress of labour, while little change was determined in the already decreased response of the depressed fetus. Acceleration of fetal heart rate (FHR) in response to vibroacoustic stimulation (VS) has been determined during labour (Richards et al. 1988). A deceleration of FHR after VS was

determined by Sarno and Major (1991) to be uninfluenced by the amount of amniotic fluid present.

A significantly depressed fetal response to acoustic stimulation (AS) has been determined in the presence of fetal and maternal risk factors (Luz 1985). The potential for measuring fetal well-being by means of AS during the progress of labour was indicated by these observations. The AST provides a valid indicator of fetal distress during labour (Ingemarsson et al. 1988, Smith et al. 1986). A VS test during the latent phase of labour indicated that response was associated with high specificity and negative predictive values, while non-response occurred in fetuses who were at a significantly greater risk of abnormal FHR patterns, meconium staining, caesarean delivery because of fetal distress and Apgar scores less than 7 at both 1 and 5 minutes (Sarno et al. 1990). It was concluded that fetal AS in the early intrapartum period may discriminate the compromised from the noncompromised fetus. Accelerated FHR response to vibroacoustic stimulation is found to be associated with favourable fetal outcome, and a nonacidotic fetal pH (Ohel et al. 1986c, Smith et al. 1986, Edersheim et al. 1987). The high incidence of acidosis associated with non-response to acoustic stimulation, indicates the value of the AST as an alternative to blood sampling (Smith et al. 1986). The AST provides a less-invasive procedure than that of fetal scalp puncture (Edersheim et al. 1987).

Any monitoring of fetal or neonatal response to AS needs to be conducted considering any medication which might influence that response. The administration of pethidine to the mother during labour is a common means of pain management. The concentration of pethidine in the blood of the umbilical cord within half an hour of the injection is found to correspond with that found in an adult in a state of clinical analgesia (Belfrage et al. 1981), while the concentrations of norpethidine observed were considered too low to affect the infant. A study by Jensen (1984d) demonstrated that FHR response to AS was depressed within half an hour of administration of pethidine in 10 out of 20 subjects and in all fetuses within 2 to 3 hours. Maternal administration of 0.8 mg/kg of meperidine, and 25 mg of promethazine has been shown to influence fetal response to VS (Zimmer et al. 1990). The stimulus was presented during a period of spontaneous or analgesia-induced low fetal FR

variability. The medicated group showed significantly less number and duration of fetal body movements and FHR accelerations after AS than the nonmedicated group. After 10 minutes, 83% of the former group had returned to a quiet state, this not being observed in the latter group.

Continuous lumbar epidural block with either lidocaine or mepivacaine is shown by Scanlon et al. (1974) not to significantly alter response to sound, excepting that less habituation to a repeated sound stimulus occurred at 2 to 6 hours of age than in infants whose mothers had received no medication. This observation was confirmed by Kangas-Saarela et al. (1987) who examined the effects of maternal segmental epidural analgesia, with a low dose of bupivacaine, on neonatal behavioural response. The only statistical differences were found at the age of 1 day, when the epidural group displayed better habituation to auditory stimuli. The use of general anaesthesia (cyclopropane and methoxyflurane) during delivery has been shown to influence auditory response of the infant up to 2 days after birth (Moreau and Birch 1974). Goodlin (1979) determined that neonates whose mothers had received caudal block or no drugs during labour, responded to acoustic stimulation from 18 min after delivery. Those delivered after caesarean section responded within 3 minutes. The 'stunned depression' of the neonate who had undergone labour and delivery was suggested to be associated with the long, 'painful' birth experience.

4.2. THE INFLUENCE ON THE FETUS OF MATERNAL RESPONSE TO MUSIC DURING LABOUR AND DELIVERY

Because of its power to affect emotional and psychological states, music is known to be used as a positive adjunct to medical procedures. MacClelland (1979) describes the value of music in the operating room, while it is shown to aid relaxation and relieve pain in dental treatment (Long and Johnson 1978).

A large number of testimonies to the use of music specifically during childbirth have been published. The pain which mothers may experience in childbirth, and the fear of medical procedures and hospital environments, which may

appear unfamiliar and threatening, are shown to be influenced by the therapeutic use of music. The positive effects of music in the training of mothers in muscular relaxation and controlled breathing techniques have been described (LaLeike 1988). Livingston (1979) determined that music enhanced relaxation and controlled breathing during labour and delivery. It has been suggested that music provides a non-intrusive, economical means of pain management during childbirth, by facilitating muscular relaxation and the use of breathing techniques; providing a distraction from pain; and providing a familiar and thus, comforting environment (Clark et al. 1981, Hanser et al. 1983). Decreased amounts of pain were reported in a study on subjects using music during labour which had been presented during 6 one-hour music therapy sessions during the pregnancy (Clark et al. 1981). The same observation was made by Hanser et al. (1983) using music as a distracting focus, a cue for rhythmic breathing and a tool for promoting relaxation. Pain perception was tested by Geden (1989), on subjects experiencing simulated labour pain, using music as a distracting focal point. Although results were not statistically significant, subjects using 'easy-listening music' (explained as harmonic, tonal music with a gentle pulse and instruments of soothing timbre) had lower pain ratings than those listening to rock music. Completed questionnaires were reported by Sammons (1984) to indicate that self-chosen music established a welcome refuge for mothers in a foreign and sometimes frightening hospital environment. In some cases, music was shown to provide a distraction from pain and to reinforce breathing rhythms.

A study by Durham and Collins (1986) determined no association between frequency of pain medication in labour and the use of music. However, Thompson (1990) determined significantly less epidurals, instrumental deliveries, episiotomies and emergency Caesarean Sections in a study group of mothers using music and a control group using no music. She further noted that the music group had a greater success rate in breastfeeding.

While most studies indicate the use of recorded music, some references have been made to active music making in the form of maternal singing:

"...singing provides a simple way for women to exercise their diaphragm muscles and learn to concentrate on breathing out, which can help them relax during labor" (Odent 1986 p27).

4.3 DISCUSSION

"When we utilise music in our classes we not only enhance the work at hand but we also inspire or reawaken a curiosity about and appreciation for the power of music, a gift which can prove to be a lifelong love and ally" (LaLeika 1988 p16).

The possibilities for therapeutic influencing of the fetus during the birth process by means of music should be researched. The influence of maternal response to music during labour on fetal outcome measures (such as, degree of medical intervention) requires confirmation in order to determine its clinical significance. However, the facilitation of relaxation, which benefits the progress of labour, is of obvious physiological benefit to the emerging baby. In the light of evidence that the fetus is affected by the emotional state of the mother during pregnancy (Ferreira 1965, Kelly 1962, Stott 1973), it is suggested that psychological effects of music on the mother (during the pregnancy and birth) may indirectly influence the baby.

The tests by Luz et al. (1980) and Luz et al. (1985) have determined that the normal fetus responds to external acoustic stimulation during labour. While the subject has been scarcely researched, the author suggests that this evidence of fetal perception of and response to acoustic stimulation during labour, indicates that music may directly influence the infant during the birth process. The responses observed in these studies are generally startle responses to the onset of a brief stimulus, indicating at least a basic sensory perception thereof.

The increasingly popular concept of 'natural' childbirth in countries providing first world medicine, has been inspired by, amongst others, the works of Odent (1984) and Leboyer (1976). The latter stresses the need to shield the baby

from harsh sounds, such as clashing medical equipment and loud shouts. In view of the evidence of fetal response to sound during birth, the author suggests the possible potential for the direct therapeutic influence of music on the emerging baby.

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NEONATAL RESPONSE TO ACOUSTIC STIMULATION

Before the 1960's, relatively few major works investigated the stimulus reception and response processes of the human neonate. The belief that a newborn could neither see, smell, taste, or feel pain was not uncommon (Preyer 1885). Kussmaul maintained that the child is born deaf (Kussmaul 1859). Such advances in knowledge of the subject have since been attained that the utilisation of neonatal sensory capacities for diagnostic and intervention purposes has become common practice. The normal human infant is born with all the senses functioning (Kessen et al. 1970, Lind et al. 1966), with the ability to imitate facial and manual gestures observed within one hour of birth (Meltzoff 1977), with the capability of conducting rhythmic dyadic interaction (Censullo et al. 1985) and the ability to localise sounds (Muir and Field 1979, Clifton et al. 1981).

A wide variety of screening methods has been devised for detecting different types of neonatal response to acoustic stimulation (5.1) Some of this research was conducted with a view to establishing, when necessary, early auditory habilitation for ensuring optimum development of the hearing function (Downs and Sterritt 1967). The risk of auditory impairment has been shown to be relatively high in infants admitted to Intensive Care Units (ICUs) (Duara et al. 1986, Stein et al. 1983, Simmons 1980). In the case of hearing deficits, the early prescription of hearing aids and special education is influential in the development of speech and language. Testing of infant hearing impairment is sometimes postponed until the age of 8 months, utilising a behavioural test involving localisation (McCormick 1983) (5.1.1). However, cases have been recorded of deaf children having passed this test,

indicating its value only when a high and sustained level of training of the tester is provided (McCormick 1983). Various methods of testing have been developed, including measurements of the central nervous system (5.1.1), the autonomic nervous system (5.1.2), behavioural response (5.1.3), auditory evoked response (5.1.4), as well as emotional and psychophysiological response (5.1.5). Response to acoustic stimulation (AS) is shown to be influenced by the characteristics of the sound source used (5.2) and the behavioural state of the neonate at the time of testing (5.3).

5.1 TYPES OF RESPONSE

Acoustic stimulation of the human neonate is shown to affect central nervous system indices (5.1.1), autonomic nervous system indices (5.1.2) behavioural response (5.1.3), average evoked potentials (5.1.4), emotional and psychophysiological response (5.1.5).

5.1.1 Central nervous system indices

The testing of central nervous system indices has included measuring components of startle response, such as the auropalpebral reflex (APR), and determining the reflex of the tympanic membrane by means of impedance audiometry.

The most constant component of the startle reflex is the eyeblink (APR) which is an easily observable response to auditory stimulus which has been consistently determined in neonates (Wedenberg 1956, Froding 1960, Hutt et al. 1968). The measure of neonatal startle response to AS was declared by Suzuki et al. (1964) to provide a reliable method for clinical audiometry. Neonatal startle response to AS (including APR, eye widening and movement) was determined by Taylor and Mencher (1972), demonstrating that nearly 80% of subjects responded after presentation of 2 stimuli.

Neonatal response to loud sounds has been referred to by some authors as the "Moro" reflex (Wedenberg 1956). Typically, the Moro

reflex is elicited by dropping the baby's head a short distance, resulting in abduction of the arms at the shoulders and extension of the forearms at the elbows. Comparing neonatal sound-evoked startle response with the Moro reflex, Bench et al. (1972) found significant differences between the two. There was less head turning, more outward, followed by inward arm movement, more simultaneous and symmetrical arm movements and more activity in the arms than in the legs in response to the head-drop stimulus. The description of all startle responses to AS as being Moro reflexes was described as clearly inadequate.

Acoustic reflex in the neonate has been well documented (Keith 1973, Keith 1975, Bennett and Weatherby 1982, Bennett and Weatherby 1979, Weatherby and Bennett 1980, Vincent and Gerber 1987, Sprague et al. 1985). Auditory reflex can be elicited even in the neonate with central nervous system disorders. Its limitation is found in the fact that a sensorineural hearing loss as great as 60 dB can still manifest acoustic reflexes (Feinmesser and Tell 1976, Brackmann and Forquer 1983). It is a reflex which can be observed only with the presentation of a high-intensity stimulus, usually at a frequency above 250 Hz (Feinmesser and Tell 1976). Middle ear muscle contraction may be described as resulting in an increased stiffness of the ossicular chain. The method for testing acoustic reflex involves inserting a probe into the ear. Fixed frequency tones are supplied to the probe tip by an oscillator and loud speaker. The intensity is set to a specific level and the external auditory meatus is sealed. Returning signals are detected by 2 microphones within the probe, connected to a comparator, where amplitude and phase analysis is carried out. The acoustic reflex of the neonate was shown by Weatherby and Bennett (1980) to be fully developed and functional at birth, with reflex threshold levels being similar to those of adults. Clear acoustic reflexes were found for all neonates examined, using probe frequencies above 220 Hz. The low impedance of the tympanogram at frequencies below about 500 Hz was cited as the reason why the acoustic reflex may not be detected with a 220 Hz tone. The low impedance drum is claimed to effectively shunt the higher impedance of the middle ear system, with the result

that small changes in impedance, such as caused by the reflex, may not be seen. The optimum range of the probe frequency for measuring acoustic reflexes was shown to be from 800 Hz to 1800 Hz. It was stated that hypotheses about incomplete myelination of the auditory pathway and residual mesenchyme in the middle ear preventing a reflex from occurring, may be discarded. Bennett and Weatherby (1982) confirmed the close agreement between adult and neonatal acoustic reflex thresholds when a 1200 Hz probe frequency was used. Reflex thresholds of neonates were shown to be approximately 10 dB higher. Vincent and Gerber (1987) determined acoustic reflexes in all subjects with normal tympanograms. As age increases from 2 days to 6 weeks, reflex thresholds are shown to decrease by an average of nearly 6 dB, more noticeably for tones than for noise. A study by Sprague et al. (1985) determined the characteristics of the neonatal acoustic reflex to be similar to those seen in adults. Findings suggested that both the ipsilateral and contralateral acoustic-reflex arcs are functional at birth. Acoustic reflex thresholds for noise are shown to be significantly lower than for tone, as with adults. Thresholds for the 220 Hz and 660 Hz probe tones were similar. Stapedial reflex in neonates is obscured by behavioural response (Keith 1978, Brackmann and Forquer 1983). Studies of normal infants have shown the presence of oto-acoustic emissions in neonates (Stevens et al. 1987, Johnsen et al. 1983, Eiberling et al. 1985).

5.1.2 Autonomic nervous system indices

Autonomic nervous system measures of response to acoustic stimulation include skin conductance, respiration and heart rate (HR) patterns. A study by Crowell et al. (1985) determined a significant average evoked heart rate (HR) response change after acoustic stimulation and it was indicated that the measure of averaged HR response to tones may function as a reliable audiometry response measure. Steinschneider et al. (1966) demonstrated consistent neonatal cardiac response to a white noise stimulus presented at 70 dB. Modulation of acoustically-elicited neonatal cardiac response was studied by Ver Hoewe and Leavitt (1985). The female voice has

been shown to elicit a neonatal cardiac deceleration (Lipsitt 1977). A study by Suzuki et al. (1964) determined significant neonatal respiratory changes associated with acoustic stimulation, including changes in rate or deepness, decrease in regularity and sudden deep inspiration. Respiration changes in response to AS were examined by Peiper (1963) and have been facilitated by the use of the auditory response cradle (Bennet and Lawrence 1980, Weir 1981). Galvanic skin reflex in neonatal response to AS was demonstrated by Crowell et al. (1965), the criteria for positive response being a decrease in skin resistance of at least 2 mm occurring within 20 sec of the onset of the stimulus and a response time for reaching maximum amplitude of no greater than 5 sec.

5.1.3 Behavioural response

A wide variety of neonatal behavioural responses to AS have been reported in the large number of papers published on the subject. Behavioural assessment has included observation of the activation, immobilisation/cessation and alteration of behaviour. Response is observed in a variety of behavioural activities, such as: eye blink, eye widening, facial grimacing, nutritive or non-nutritive sucking activity, head turn towards the stimulus (localisation), stretching of the head and neck, movement of fingers, hands, limbs, trunk, and shoulders.

Positive response to an auditory stimulus has been defined by the Nova Scotia Conference on Early Identification of Hearing Loss as 'any generalised body movement which involves more than one limb and which is accompanied by some form of eye movement' (Mencher 1976). Using this criterion in observing auditory arousal in preterm infants, Gerber et al. (1983) determined a positive response in 24% of the trials, occurring within 2.5 sec of the stimulus onset, in a minimum of 2 out of 8 trials. A comparison between auditory arousal in preterm and full term neonates determined more response in the preterm infant (Gerber et al. 1983). Gerber and Dobkin (1984) determined positive neonatal arousal response to various high-pass filtered noises in 40%

to 53% of subjects tested. In assessing a variety of behavioural responses, Lichtig and Wells (1980) found that almost any form of auditory stimulation produces an increase in visual activity. Different sound sources caused varying degrees of hand and head movements and different amounts of body and facial activity. The intrusion of AS during non-nutritive sucking, has been shown to disrupt the sucking pattern (Semb and Lipsitt 1968). The auditory response cradle (ARC), developed by Bennett and Lawrence (1980) was used by Weir (1979) and Weir (1981) in observing body activity, head turn and backward head movement (startle). Equivalent responding for auditory and tactile stimuli was observed, which significantly exceeded response during periods of no stimulus. The behavioural test, with the aid of the auditory response cradle, is described by Weir (1985) to provide a suitable initial screening device for hearing impairment. The 'crib-o-gram' involves a similar means of assessing behavioural response (Simmons and Russ 1974). The motion-sensitive transducer, placed beneath the crib, is described as being able to detect any motion stronger than an eye-blink. It provides a completely automated method for screening for deafness.

The effects of acoustic stimulation on cessation and initiation of non-nutritive sucking in neonates has been demonstrated by Semb and Lipsitt (1968). The suppression of crying can be elicited with an acoustic stimulus, which provides a distraction for the baby. Ricillo and Watterson (1984) demonstrated that the presentation of a cry (a recording of either the neonate's own cry or another cry) caused significantly less crying in a test group than in a control group exposed to no acoustic stimulation. Neonatal response to a tape recording of another newborn cry, and a computer-simulated cry was compared in a study by Simner (1971). The profusion of crying and restlessness which coincided with the former was not evident with the latter, indicating that the response is influenced more by the tone colour or texture of the sound than by its intensity. The suppression of neonatal crying was demonstrated by Watterson and Riccillo (1983) to be more effective when presenting a random noise stimulus than a female voice

stimulus, which in turn, was more effective than no stimulus presentation.

Neonatal movement has been shown to be synchronous with adult speech, suggesting a view of the neonate as a participant in interactional organisation from birth (Condon and Sander 1974).

Localisation is a primary aspect of auditory function, shown to be within the capabilities of the neonate (Muir and Field 1979, Turkewitz et al. 1966). The neonate makes eye movements or head turns which are spatially coordinated with the location of sound, indicating spatial coordination between the auditory and oculomotor systems from birth (Castillo and Butterworth 1981, Muir and Field 1979, Weiss et al. 1988). Results differ across trials, with measures of correct head turning varying from 46% (Clarkson et al. 1985) to 87% (Muir and Field 1979). The shaking of a bottle partially filled with popcorn elicited correct neonatal head turning in 79% of trials conducted by Field et al. (1980). The incidence of spatially-coordinated response is shown to be dependent on neonatal behavioural state, the characteristics of the stimulus (nature, intensity and duration) and the lateral-stimulus-presentation probability (ie. the level at which the stimulus is presented). It is enhanced by the presence of a visual target (Clarkson et al. 1982, Castillo and Butterworth 1981). A test by Wertheimer (1961) demonstrated ability of the neonate to localise a sound before 10 minutes after birth, indicating that localisation is not a 'learned' experience. The use of the rattle sound employed in the Neonatal Behavioural Assessment Scale (Brazelton 1984) has reliably elicited neonatal head turns (Muir and Field 1979, Clifton et al. 1981). The study by Clifton et al. (1981) determined 58% head turning in response to the presentation of a single sound source, with correct localisation in 95% of these responses. Studies of stimulus parameters continue to provide information regarding the delineation of the primary stimulus characteristics in the eliciting of head orientation. A reduction in the probability of lateral presentation coincides with a deterioration of correct head turning (Clifton et al. 1981, Morrongiello and Clifton 1982,

Clarkson et al. 1982). The number of stimulus bursts and the stimulus duration are also shown to influence neonatal head orientation (Clarkson et al. 1991).

5.1.4 Electroencephalographic response

In the study of average evoked auditory potentials, scalp electrodes record electrical activity while a computer amplifies the information, passes it through frequency filters, adds the information and averages it. The test provides a measure of neurological assessment which is stable under a variety of environmental conditions and behavioural states, being unaffected by sleep states, coma, attention, sedation or mild hypoxia (Plessinger and Woods 1986, Mosko et al. 1981, Starr and Achor 1975, Sohmer et al. 1978, Picton et al. 1974a). Obtaining average evoked potentials provides an alternative method of assessing neonatal auditory function in infants who are unable to participate in conventional behavioural testing (Zubick et al. 1982). The suitability of electrocochleography for early diagnosis of hearing loss was demonstrated by Lieberman et al. (1973) and the results are shown to be more accurate than screening by means of the 'crib-o-gram' (Shimizu et al. 1985). In the assessment of hearing sensitivity and auditory maturation by means of brain stem auditory evoked potentials, it has been established that replication elicits minimal latency variation, indicating the suitability of the method in the screening of large numbers of infants (Zubick et al. 1982). Studies indicate possible sites of origin of the waves which are components of the response, but these are still being questioned (Plessinger and Woods 1986).

The most widely used average evoked potentials are the early components (0 msec - 10 msec latency), in particular, the auditory brain stem response (McRandle et al. 1974, Paludetti et al. 1981). Auditory brain stem response (ABR) is the neuroelectric response of the auditory system in the brainstem and midbrain to sound stimulation. By investigating ABR, functions of peripheral auditory apparatus (middle ear and cochlea) as well as the central auditory

pathway through the brain stem are able to be quantified (Lary et al. 1985).

Hearing thresholds of neurologically optimal neonates have been determined by applying the criterion of the presence of wave V in auditory brain stem response (Lary et al. 1985). These were found to be 40 dB between 28 and 34 weeks gestational age; 30 dB between 35 and 38 weeks; and below 20 dB in term infants. It was cautioned that difficulty in obtaining hearing thresholds may occur in infants with neurological problems, such as severe asphyxia, hyperbiliribinaemia or periventricular haemorrhage. Roberts et al. (1982) determined the presence of Wave V in 50% of neonates tested at 32 weeks when the stimulus was presented at 70 dB, and in 50% of neonates at 40 weeks when presented at 40 dB. It was reported that latencies decrease with age, with the latency of wave V shortening from about 9.3 msec at 32 to 33 weeks gestational age, to about 7.6 msec at 40 weeks. A study by Starr et al. (1977) determined that wave V decreases from 9.9 msec at 26 weeks gestation to 6.9 msec at 40 weeks. Central conduction decreased from 7.2 msec at 26 weeks to 5.2 msec at 40 weeks.

The quality of central processing of auditory information, may be examined beyond the limit of the brain stem. Middle latency (MLR) components (10 msec -50 msec) and the late components (50 msec-500 msec), observed in auditory cortical responses (ACRs), are generated at and above the level of the mesencephalon and are therefore of interest in the study of neuroaudiology (Rotteveel et al. 1986). Latency and amplitude can be well-defined in ABRs but not in cortical evoked responses (Starr and Achor 1975). Low and high frequency hearing in neonates has been assessed by means of the MLR (McRandle et al. 1974, Wolf and Goldstein 1980). A study of MLR in neonates by Shallop and Osterhammel (1983) concludes that evaluation of low-frequency hearing (which is less successful in ABR testing) can be obtained by means of the MLR. A comparison between ABRs and MLRs by Ueda (1990) determined almost equal threshold in

response to a click stimulus and a difference less than 10 dB in response to a tone pip stimulus, being slightly worse for the MLRs. Late components are recorded by Crowell et al. (1980). The study of ACRs was declared by Rotteveel et al. (1986) to be somewhat unreliable for purposes of determining hearing threshold (for which ABRs are more successful), but it was suggested that ACRs were suitable for studies on the perceptual aspects of hearing.

5.1.5 Emotional and psychophysiological response

The soporific effects of the lullaby are well-known. Rhythmic rocking or rhythmical sounds, such as the ticking of a clock, are widely believed to calm the newborn baby. The presentation of a recording of a mother's heart beat was shown by Salk (1962) to facilitate longer periods of quiet sleep and, hence, greater weight gain in both premature and full-term neonates. Almost any continuous, low-frequency sound is shown to lower the activity and arousal levels of the infant (Peiper 1963, Brackbill et al. 1966). While high frequency sounds up to 4000 Hz occasion distress, low-frequency pure tones up to 500 Hz and low-pass filtered noise at 1350 Hz tend to have a soothing, inhibiting effect (Eisenberg 1976, Brackbill et al. 1966, Birns et al. 1965, Birns et al. 1966, Bench 1969).

Several studies have demonstrated the psychophysiological effects of auditory stimulation on the premature infant, questioning whether the artificial environment of the life-preserving incubator may constitute a prison of sensory deprivation (Katz 1971, Kramer and Pierpont 1976). Furthermore, the auditory stimulation experienced in the ICU has been described as noxious (Weibley 1989). Considering detrimental effects of noise on fetal growth, these accusations should be taken seriously (Schell 1981, Ando and Hatorri 1977). Infants graduating from the incubator are already 'high-risk' regarding hearing impairment. Besides the obvious physiological reasons for this predisposition, questions have been raised regarding the damage which could be caused to hearing by the noisy environment of the ICU (Douek et al.

1976). The noise levels in incubators vary, with some measurements recorded from 57 dB to 74 dB (Falk and Woods 1973). Frequency analysis of incubator noise indicates sound pressure levels not unlike those occurring in the uterine environment, which consist of predominantly low-frequency sounds (Falk and Woods 1973, Douek et al. 1976). However, some studies refer to the exceptionally high noise levels of machinery, telephones, monitor alarms, refuse receptacles, etc. commonly found in neonatal ICUs (Weibley 1989). In creating a sterile environment, the infant is not only isolated from infectious organisms but from the multi-faceted stimuli which exist in the pre- and postnatal environments. Katz (1971) determined that the mother's voice, presented for 5 minutes, 6 times daily, resulted in increased levels of maturation (assessed by the Rosenblith Modified Graham Behavior Scale, 1961). The motor delays frequently reported in preterm infants may be addressed by supplemental auditory and other sensory stimulation, which appears to facilitate motor development assessed by means of developmental tests (Katz 1971). A combination of rocking waterbeds and auditory stimuli were shown by Kramer and Pierpont (1976) to enhance growth of preterm infants.

5.2 SOUND SOURCES FOR NEONATAL ACOUSTIC STIMULATION

The neonatal response to acoustic stimulation (AS) is shown to be influenced by the nature, intensity, duration and frequency of the stimulus.

It is widely agreed that high and low frequencies elicit different effects on the human auditory system, as well as on physiological and psychological response. Broad band signals are more effective as a stimulus in eliciting consistent behavioural response than pure tones or narrow band sounds (Gerber and Dobkin 1984, Gerber et al. 1983, Taylor and Mencher 1972, Turkewitz et al. (1966). The test by Weir (1981) of neonatal motor and respiratory response using the auditory response cradle involves the use of a white noise stimulus. Combinations of tones, which were ineffective when presented independently, were shown by Turkewitz et al. (1972b) to elicit

response. Startle response to square wave tones is more easily elicited than to sine wave tones of the same frequencies (Hutt et al. 1968). Acoustic reflex thresholds are shown to be significantly lower for broad band noise than for a 1000 Hz tone (Sprague et al. 1985, Vincent and Gerber 1987). Response ratios are shown to be influenced by the use of a patterned stimulus (such as speech) or unpatterned stimulus (Hutt et al. 1968, Eisenberg et al. 1964). However, a study by Suzuki et al. (1964) determined no difference in neonatal startle reflex to a pure tone of 500 Hz and to an artificial sound of a cow mooing.

Lower frequency pure tones elicit more response than higher frequency pure tones or narrowband sounds centered around higher frequencies (Hutt et al. 1968, Eisenberg 1976, Ling et al. 1970). The study by Gerber and Dobkin (1984) determined neonatal arousal response in 53% of trials with a 500 Hz high-pass filtered signal and in 40% of trails with a 2000 Hz high-pass filtered signal. Simmons and Russ (1974) reported presentation of a 2 Hz to 4 KHz band of noise at 92 dB in the 'crib-o-gram' test. A review by Weir (1985) on behavioural response cites the use of high-pass filtered noise stimuli, presented at 85 dB, and narrow band noise stimuli at 3 kHz, presented at 90 dB. The APR of the neonate was elicited in all subjects tested in the study by Wedenberg (1956) to frequencies of 500 Hz to 40000 Hz, presented at a level of 105 dB-115 dB.

The optimal frequency range required for screening for deafness has been determined in order to avoid having hearing-impaired infants respond to the low-frequency components of a signal and some infants with normal hearing failing to respond to high frequency sounds from 3000 Hz. The Nova Scotia Conference on Early Identification of Hearing Loss (Mencher 1976) recommended the optimal stimulus for obtaining behavioural response in auditory screening as 'a random noise having a low frequency attenuation of 30 dB or more per octave below 750 Hz; a maximum of 90 dB sound pressure level at the pinna; a rise-decay time of 5 ms or more; a duration of 0.5 to 2 sec; and an inter-test interval minimum of 15 sec'.

Weatherby & Bennett (1980) suggested that the optimal frequency range for the probe tone used in auditory reflex measurement was between 800 Hz and

1800 Hz. Auditory evoked response is usually elicited by clicks, which have the limitations of not being frequency-specific, and of evaluating only at higher frequencies (Morgan et al. 1987, Lary et al. 1985). Some studies, however, include tone-pip evoked ABR (Ueda 1990, Yamada et al. 1983).

A study of reflex modification concluded that the neonate is able to process tones within the same intensity range as the adult (Anday et al. 1988). Increased response ratios to a corresponding increase in stimulus sound pressure level were indicated by Steinschneider et al. (1966). Consistent response was determined when the stimulus was presented at a level of at least 70 dB. Other studies confirm that cardiac acceleration is a function of sound intensity (Bartoshuk 1964, Eisenberg 1976). Pure tones of high frequency are shown to be more disturbing than pure tones of low frequency (Eisenberg 1976). An inverse relationship between stimulus intensity and latency of brainstem auditory evoked responses has been reported (Lieberman et al. 1973, Collet et al. 1988). The study of cardiac response to AS by Steinschneider et al. (1966) used a white noise covering a spectrum from 20 Hz to 20000 Hz, indicating increasing cardiac responses corresponding with increasing intensity levels. Latencies of auditory brain stem responses vary systematically with intensity (Hecox and Galambos 1974). Localisation of auditory stimulation is shown to be dependent on the nature, intensity and duration of the stimulus and on the probability of lateral presentation (Castillo and Butterworth 1981). However, a study by Clarkson et al. (1985) determined that head orientation response of the neonate was not altered by increasing the duration of a signal from 1 sec to 20 sec.

5.3 INFLUENCE OF NEONATAL BEHAVIOURAL STATES ON RESPONSE TO ACOUSTIC STIMULATION

"In the human newborn, the probability and magnitude of a response to a given stimulus is almost without exception a function of state" (Hutt et al. 1969 p164).

Lichtig and Wells (1980) caution that the state of the neonate needs to be taken into account, but that it need not be an obstacle to assessment of startle auditory response (apart from applying a stimulus when the infant is distressed). The amount of response would be less in state 1 (deep sleep) than in state 4 (alert awake). The optimal state for the determining of neonatal startle response, was found by Taylor and Mencher (1972) to be light sleep. It was explained that this state avoided the distractions which occur from other sensory stimuli in the awake state, while the neonate was not so deeply asleep as to be in a state of sensory oblivion. This concurs with an investigation by Anday et al. (1988), where neonates were shown to be less responsive in quiet sleep than in active sleep. The study by Hammond (1970) determined that the optimal state for observation of neonatal head turning to an auditory stimulus was state 3 (quiet awake). The incidence of spacially-coordinated response is shown to be dependent on neonatal behavioural state (Castillo and Butterworth 1981).

In order to obtain consistent acoustic reflex thresholds, it is found to be difficult but not impossible to do so, unless the infants were asleep (Vincent and Gerber 1987). The early components of auditory evoked potentials (ABRs) are unaffected by behavioural states (Plessinger and Woods 1986, Mosko et al. 1981, Sohmer et al. 1978), unlike the middle and late components which are shown to be subject to the influence of sleep states (Picton et al. 1974a, Picton et al. 1974b).

5.4 DISCUSSION

The concept that music influences the neonate has been accepted in societies of many ages and cultures. The lullaby and rhythmic rocking are widely integral to newborn care. The presence of normal acoustic reflex in the neonate, the behavioural and electroencephalic response, and responses of the central and autonomic nervous systems to AS, together indicate that the neonate is able to perceive and respond to sounds of many descriptions. As is the case in fetal perception of sound, the emotional and psychophysiological perception of sound in the neonate is less thoroughly researched. However, effects of reduced crying and lowered activity levels

associated with acoustic stimulation are indicative of the power which music might have on the newborn. While the physiological responses of the infant provide evidence of perception and attention, they do not indicate detail of cognition. However, in view of the evidence of neonatal sensory perception of and response to sound, the author speculates that music may exert some influence on the human at birth.

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PRENATAL AND POSTNATAL AUDITORY DISCRIMINATION, MEMORY AND LEARNING

"Our ears are marvellous instruments but they are equalled and in some respects excelled by those of some lower mammals. It is the related brain developments that are responsible for the musician's ability to train his powers of auditory discrimination, analysis and imagery. Where a musician speaks of someone having 'a good ear', the neurologist might speak of his having good auditory 'receiving' and 'association' areas of cortex" (Phillips 1977 p51).

"We have little idea of the nature of the long-term brain-storage of a complex piece of music...before it is ever exteriorised" (Phillips 1977 p49).

A wealth of research conducted on the fetus and neonate confirms that pre- and postnatal infants are far in advance of the 'tabulae rasa' (ie. blank slate) label previously attributed to them. The human infant is born with all senses functioning (Kessen et al. 1970, Lipsitt 1977), these having been developed during the intrauterine stage (Hill et al. 1983). The auditory stimulus reception and response processes of the fetus and neonate have been widely investigated (chapter 3, 4 and 5).

Music exists in the passage of time. Perception of music must depend on a cognitive ability to link a present sound with the sound of the past. Current

scepticism regarding the possibilities of musical education of the fetus and neonate may be the result of theories of music educationalists such as Moog, who claims that the neonate

"can hear sounds, but he cannot make the connection between a sound which he perceives at a given moment and a sound which he may have perceived immediately before it. For the baby, the experience of the sound dies away immediately with the cessation of the stimulation. Therefore, a baby cannot differentiate between slow and quick music. The rhythm of any music played to a baby of this age has no significance for him" (Moog 1976 p39).

Assessment of the cognitive, psychological and emotional processes involved is a task made challenging by the limited communicative ability of the fetus and newborn. Despite this, many studies have illuminated the extent to which cortical or subcortical functioning is present in early infancy. The startle response (measured in terms of auropalpebral response, whole-body flinch and heart rate change) to externally-presented acoustic stimuli (reviewed in chapters 3, 4 and 5) represents a basic neurophysiological form of perception. More advanced perceptual tasks provide evidence of fetal and neonatal auditory processing.

The first step in learning is attention, as usually only what is attended to is learned and remembered. Attention itself involves selection and filtering of features of stimuli.

"Infants are not simply passive recipients of experience but appear to be active, searching and selective perceivers" (Bornstein 1989 p450).

A stimulus will, typically, elicit attention. Repetition of that stimulus will (if neither rewarding or threatening) cause the orientation to attenuate. A novel stimulus will again elicit attention. Evidence of discriminatory ability can be determined by achieving habituation to a stimulus and dishabituation to a modification of that stimulus. The learning process (the modification of behaviour in response to experience) involves memory, the ability to store a perception over a period of time. Learning may require a comparison of the present with the remembered past; discrimination of the similarities or differences between the two; analysis of the significance of the experience and categorisation thereof (Harris 1983, Reznick 1989,

Suzuki et al: 1964). Neonatal movement has been shown to be synchronous with adult speech (Condon and Sander 1974).

6.2 AUDITORY MEMORY

A variety of literature sources (some anecdotal and some empirical) provides indication of prenatal auditory memory and/or learning. The experiences of psychiatrists and psychologists involved in primal therapy and 'rebirthing' techniques refute the past general conviction that the fetal or neonatal brain is insufficiently developed to experience intrauterine life and birth psychologically or emotionally. A lack of clinical evidence on the subject restricts conclusions, but there are indications that, with the facilitation of drugs and hypnosis, prenatal and birth memories can be revived from the subconscious mind (Grof 1976). Suggested fetal experience of physical and psychological suffering (such as placental insufficiency, maternal intake of toxins, chronic maternal stress, compression, pain, entrapment and injury) is relived in a 'safe setting', allowing accumulated distress to be discharged (Neighbour 1981).

"It is logically and empirically possible for the infant to experience a painful episode in, for example, the third day of life which could have an effect upon his perception of subsequent events in the same day or in the next, and for these altered perceptions to influence (condition) other experiences. Yet by the time several days or years have passed, although none of the experiences would have been remembered specifically, the painful episode and its sequelae nonetheless might have altered the organism in certain special ways" Lipsitt (1977 p175).

Some of the copious anecdotal evidence of neonatal memory of sounds heard prenatally has been published, such as the case in which a set of parents spent several hours during the early stage of labour playing backgammon. For a period of four months after birth, the characteristic clicking sound of the game caused the baby to awake and cry in distress (Birch and Birch 1988). It is speculated that the baby associated the sound with possible traumas of the birth process. Naidoo (1988) reported that, during her pregnancy, her 6-year-old son practised the violin while she was involved in various activities.

For 7 months after birth, her newborn would cease any crying and adopt a quiet alert state when the older son played the pieces which he had been practising during the pregnancy. In his book, "The Secret Life of the Unborn Child", Thomas Verny (1981) describes an account of Boris Brodt, conductor of the Hamilton (Ontario) Philharmonic Symphony Orchestra. He had an uncanny knowledge of certain scores previously unseen. On reporting this to his mother, he learnt that she, as a 'cellist, had practised these particular pieces while pregnant.

Prenatal auditory environment is shown to influence the auditory response and preference of the neonate, indicating perception, discrimination and memory of sounds heard prenatally. The effect of maternal heartbeat on the newborn was measured by Salk (1962) and the results implied a memory of this sound. He presented continuous recordings of a normal heartbeat at 72 b/m, day and night, in a hospital nursery. Results were compared with a control group of neonates who were not exposed to the recording. Weight gain was significantly higher in the group receiving the heartbeat stimulus. As food intake was not different between the groups, it was assumed that the increased weight gain in the study group was the result of reduced crying. This was verified by periodic recordings of the nursery sounds. Murooka et al. (1976) reported that recordings of uterine sounds caused calming of 83,9 % of newborns. When exposed to only heart sounds, 33 % became calm. This finding was confirmed by Rosner and Doherty (1979). Lind (1980) maintains that any sound which is suggestive of the heartbeat (such as the rhythmic ticking of a clock) can be recognized as having a calming effect on the newborn. A study by Suzuki et al. (1964) suggested that increased neonatal sensitivity to a slower rate was due to it being within the range of the maternal cardiac rate to which the fetus was exposed before birth.

Querleu et al. (1984) determined neonatal discrimination of the maternal voice immediately after birth. No postnatal experience of the mother's voice was allowed prior to testing. The neonatal segmental response and orienting response to voices of similar character was observed, providing evidence of significantly greater response to the maternal voice, thus indicating prenatal perception of the maternal voice. Differential responding to the mother's voice

and that of a stranger was determined by Hammond (1970), observing neonatal turning towards the sound of the baby's name (which the mother had been using since the day of the birth). A study by Segall (1972) involved the daily presentation of 30-minute recordings of the maternal voice to premature, incubated infants. After completion of the programme, the study infants displayed greater attentiveness and heart rate deceleration to the mother's voice than control infants. A study by Damstra-Wijmenga (1988) revealed neonatal attentiveness to the maternal voice, but none to that of another woman.

Presenting different sound patterns produced by one voice, Spence and DeCasper (1982) determined that the neonate discriminated between a story which had been repeatedly read during the pregnancy and another which had not been previously presented. The mothers had been instructed to read Dr Seuss' book "The Cat in the Hat" twice daily during the last 6 weeks of pregnancy. Presenting this and another story entitled "The King, The Mice and The Cheese", also by Dr Seuss, it was indicated that the neonates discriminated the 'known' story. Mehler et al. (1988) determined that newborns distinguish utterances in their native language from those in a foreign language. There was no evidence of discrimination of contrasting utterances involving two unfamiliar languages.

External sounds presented before birth are also shown to elicit differential responding in neonates. A group of newborns who had been exposed to a 'tooter' noise twice daily for the final 4 weeks of pregnancy, were tested with a presentation of that sound. Most displayed no reaction to the noise, while a third was slightly startled. In contrast, two thirds of a control group, who had not previously heard the sound, were notably startled. It was concluded that a baby can become familiar prenatally with aspects of the external sound environment (Damstra-Wijmenga 1988). In a study by Hepper (1988), a group of newborns was exposed to the theme of a popular television 'soap opera'. The study group of mothers had watched the programme daily during their pregnancies in a relaxed state. The music had the effect of stopping crying and causing an alert state in most of the newborns. The control group, not previously exposed to the television programme, showed little reaction. Crying continued and fewer babies became alert.

6.3 AUDITORY LEARNING

Learning is a process in which behaviour is altered over time, through experience. Three specific types of learning are addressed, these being habituation (6.1), conditioning (6.2) and operant learning (6.3).

6.3.1 Habituation of fetal and neonatal response to AS

Habituation is a progressive decrease in response to a repeated stimulation. Because the process involves a change in behaviour as a result of experience, it is considered to be a form of learning (Thompson and Spencer 1966, Clifton and Nelson 1976, Mayes 1989). Habituation of response to a stimulus requires perception and memory of the stimulus, the ability to relate the present stimulus to one experienced previously and to analyse its significance. Habituation indicates a significant neurophysiological function involving auditory discrimination and short term memory, as well as adaptation to environment. In an environment of continuous stimulation, the ability to ignore non-noxious stimuli is crucial for human functioning and survival. Dishabituation (recovery of response) precludes the possibility of fatigue being the cause of the decrease in response and indicates ability to discriminate the change in the stimulus (Cohen and Gelber 1975).

The phenomenon of habituation is used by neonatologists in the establishment of neonatal cerebral function and integrity (Brazelton 1973). A normal habituation pattern is considered to reflect an intact and functioning central nervous system (Lewis 1971, Jeffrey and Cohen 1971), thus the observation of habituation provides a means of assessing central nervous system integrity (Wallace et al. 1982). Highly significant differences in habituation patterns have been observed between normal fetuses and those in a group of high-risk pregnancies (Leader et al. 1982). It was suggested that the test may offer a method of assessing the integrity of the fetal central nervous system. Leader et al. (1984) determined a correlation between a normal habituation

pattern in the fetus and significantly better performance assessed by the Griffiths Mental Developmental Scale at 1 year of age, compared with those with an abnormal pattern of habituation.

A study by Leader et al. (1982) found that 37 of 40 normal fetuses habituated within 10 to 50 vibroacoustic stimuli which lasted 5 seconds each. Dishabituation was observed in almost 80 % of subjects when a second vibrator of differing frequency was introduced. This indicates a discriminative ability in distinguishing one vibroacoustic stimulus from another. Aiming to obtain neonatal habituation of behavioural response to AS, Keith and Bench (1978) found that 5 presentations of a 1000 Hz tone, a 2600 Hz low-pass noise and a broad band noise were not sufficient to elicit habituation. Shalev et al. (1989) reported habituation in 85% of fetuses after less than 20 presentations of a 2-second low-frequency broadband noise and in 95% of fetuses after less than 30 stimuli. Ultrasonic scanning was used by Wallace et al. (1982) to determine habituation of movement response to a vibro-tactile stimulus. In a test group of normal fetuses from 32 weeks gestation to term, 77% habituated within the presentation of 10 stimuli, while 95% habituated in less than 20 stimuli. Habituation of behavioural responses to acoustic stimulation was determined by Field et al. (1979) in term and preterm neonates but habituation of cardiac responses was determined only in the term neonates. The lack of cardiac habituation was ascribed to possible insult experienced by the preterm neonates or to behavioural state. Bartoshuk (1962) demonstrated habituation of neonatal cardiac acceleration to AS, a response which was recovered with presentation of a change in the intensity of the stimulus or in the tonal pattern. Habituation of neonatal heart rate response to auditory stimulation was also determined by Graham et al. (1968). Other tests of discriminatory auditory ability using the habituation paradigm are described in chapter 6.1. The intrusion of AS during non-nutritive sucking has been shown to disrupt the sucking pattern (Semb and Lipsitt 1968) and, in some cases, habituation of this response occurs with repeated presentation. A further example of habituation was observed in tests by Leventhal and Lipsitt (1964) in which recovery of

the habituated response was obtained by presenting the stimulus from an alternate location.

Habituation is subject to gestational age, behavioural state, the nature of the stimulus, the use of medication and pathology. More effective inhibition of neonatal behaviour has been determined to a low-frequency tone than to a high-frequency tone (Watterson and Riccillo 1985, Birns et al. 1965). The use of medication which affects the central nervous system is associated with impaired fetal and neonatal habituation, such as the maternal administration of barbiturates, pethidine or anaesthetics (Brackbill et al. 1974, Moreau and Birch 1974). The intrapartum administration of continuous lumbar epidural block with either lidocaine or mepivacaine is shown by Scanlon et al. (1974) to correspond with less neonatal habituation to a repeated sound stimulus between 2 to 6 hours of age than in infants whose mothers had received no medication. The effects of maternal segmental epidural analgesia on neonatal habituation was studied by Kangas-Saarela et al. (1987) at the ages of 3 hours, 1-2 days and 4-5 days. No statistical differences were observed between the study group and a control group, except at 1 day when better habituation was observed in the study group. Habituation is impaired in high-risk fetuses and in those tested within an hour of maternal smoking of a cigarette (Leader and Baillie 1980, Leader et al. 1982b). Pathological conditions of the central nervous system, occurring in anencephalic, autistic and Down's Syndrome infants are also reported to coincide with impaired habituation (Hutt and Hutt 1965, Barnet et al. 1974, Brackbill 1971). The state of the fetus or neonate influences habituation rates. Lecanuet et al. (1986) tested fetuses of 37 - 40 weeks and determined that FHR and movement response always diminished with stimulus repetition, but did so more markedly during periods of low variability FHR patterns than high variability. Longer habituation rates were determined by Wallace et al. (1982) to coincide with higher states of arousal. Analysing the correlation between arousal state and fetal habituation, Shalev et al. (1990) determined that although fetuses in a lower arousal state habituate more rapidly to a sound stimulus, the

difference is not significant. Measuring behavioural startle reactions, Kuhlman et al. (1988) observed a trend towards greater habituation with advancing gestational age. Results ranged from responsive fetuses of 26/27 weeks, in whom no habituation was noted, to an 87% habituation evident in fetuses at 38/39 weeks. This corroborates the study by Shalev et al. (1989) which reported decrease of habituation rate with advancing gestational age, ranging from 43 presentations of the stimulus at 32 weeks to 25 presentations at 34 weeks and 10 presentations at 39 weeks.

6.3.2 Classical conditioning

The process of conditioning involves a more advanced neurological function than that involved in habituation. A new response is recruited to a previously neutral stimulus. Conditioning of response to AS has even been determined in the fetus (Spelt 1948). Initially, fetal movement response to a loud noise and lack of response to a vibration were determined. Thereafter, the noise and vibration were presented simultaneously, at least 15 times. Following this, the activation of the vibrator alone elicited movement response.

Classical conditioning of neonates was achieved in a study by Marquis (1931). During the first 10 days after birth, a buzzer was sounded prior to the offering of a bottle nipple. A period of only 5 days was required to elicit sucking response to the auditory stimulus. A test was conducted by Lipsitt and Kaye (1964) in which simultaneous presentation of a low frequency tone with the insertion of a nipple into the neonate's mouth resulted in classical conditioning. Papousek (1961) demonstrated the ability to elicit elaboration and extinction of conditioned reflexes. The investigation included the combination and separation of two stimuli, namely a nutritive nipple and a bell sound. Aldrich (1928) demonstrated classical aversive conditioning by pairing a bell sound with a pin-prick to the sole of the foot. Only 12 to 15 such pairings were required for the bell to elicit the response associated with the pin-prick.

6.3.3 Operant conditioning

Operant conditioning is the negative or positive reinforcement of a response, involving reward or punishment. Behaviour is modified by the experience. Several studies of neonatal operant conditioning have been conducted, with regard to parameters other than auditory (Sameroff 1972, Kobre and Lipsitt 1972). Auditory operant conditioning has been investigated in the infant of 2 to 3 months of age (Eimas et al. 1971), demonstrating that the infant will suck in order to hear auditory stimuli. One- and two-day old infants have been shown to change sucking patterns to activate a recording of a singing group and a recording of a female vocalist (Butterfield and Siperstein 1972, DeCasper and Carstens 1981). In a study by DeCasper and Sigafos (1983), the neonate triggered the presentation of recorded intrauterine heartbeat sounds by altering sucking behaviour. The operant learning task required that the neonate either shorten or lengthen the inter-burst sucking interval, in order to hear a recording of the intrauterine heart beat. By selecting and continuing with the required method, the reinforcing capability of the associated sound was indicated. In order to confirm results, the test was repeated with sucking requirements reversed. The heartbeat recording was shown to be an effective reinforcer of neonatal response and it was suggested by the authors that the results indicated recognition of sounds previously heard in utero. A further study involved the altering of sucking behaviour in order to activate one of two possible sounds. Besides indicating discrimination, the same sucking test was used to indicate preference, meaning that the one sound was more reinforcing than the other. Neonatal activation of two recordings, one of the maternal voice and one unfamiliar, indicated preferential selection of the former (DeCasper and Fifer 1980). The same operant learning task was used to observe that both paternal and nonpaternal voices were ineffective reinforcers and no preference was indicated for either one (DeCasper and Prescott 1984).

6.3 DISCUSSION

Just how much of their acoustic environment do the fetus and neonate process cognitively? Evidence of the extent of auditory memory and learning which exists in these early days of life is gradually emerging. Investigations reviewed in this chapter are largely pioneering studies which give indication of auditory discriminatory and learning abilities in the fetus and neonate.

While the normal human possesses the discriminational senses required for perception of music (in terms of pitch, pulse, rhythm, timbre etc.), it has not been established exactly how early these specific abilities are developed. However, it appears to be already within the capabilities of the neonate to discriminate certain differences in duration, rhythm, intensity, pitch and timbre. These being the basic components of music, it is speculated that the fetus and neonate may well be able to discern noise from music and certain musical sounds from others. While some sounds appear to be inherently stressful (eg. a drill) or soothing (eg. the cooing of a dove), the cognitive or emotional perception of some sounds as 'noise' or 'music', 'pleasant' or 'agitating' may conceivably be the product of learning and conditioning. While it appears that the fetus and neonate may be able to discriminate certain musical sounds from one another, how that music is initially perceived is currently a matter of speculation.

Considering the short-term memory of sound which is required in order to perceive music as a sequence of sounds and silences, the literature provides prolific evidence of auditory memory during the postnatal stage and some during the prenatal stage. The adjusting or conditioning of response as a result of auditory experience demonstrates ability to remember a sound, to relate the present sensory experience to a previous one, and to interpret the information received in terms of its noxious or rewarding effect. The resumption of response after habituation, which coincides with the presentation of a novel stimulus (differing from the repeated stimulus), indicates discriminatory ability between two auditory stimuli.

"Learning experiences in early life may have enduring effects on the capacity of the central nervous system to hold information in memory and to capitalise on that capacity for further learning" (Lipsitt 1986 p174).

Fetal and neonatal cognitive capacity for auditory learning beyond short term periods is also indicated by the studies of neonatal response to sounds from the intrauterine acoustic environment. Theories of fetal experience and memory of sounds have led to the worldwide establishment of a variety of fetal, infant and adult educational and therapeutic practices which incorporate the use of music. Two well-known examples are the USA Prenatal University of Hayward (Peri 1986, Westcott 1987) and the Tomatis Method (Tomatis 1981). However, the effect of prenatal familiarization, specifically to music within the environment, still needs extensive investigation. Is musical experience in the pre- and post-natal periods a precursor of musical excellence? While current knowledge of the subject is still limited, the author suggests that the presence of music in the fetal acoustic environment provides the fetus with musical material for any learning potential which may exist.

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SECTION 2

RESEARCH

CHAPTER 7

THE TRANSMISSION OF PURE TONES, VOICES AND MUSIC INTO THE UTERUS

7.1 ABSTRACT

The intrauterine acoustic environment was recorded by means of a hydrophone inserted through the cervix, next to the fetal head. The study was conducted on eight women in early labour, four before and four after rupture of membranes. The average residual uterine sound of all eight subjects was measured at 65 dBA (A-weighted) re 20 μ Pa in a 10 KHz band, RMS averaged over 32-second records. Above this emerged the maternal voice, an external female voice and a male voice presented at approximately 65 dB, as indicated on the linear scale of the sound level meter. Pure tones between 50 Hz and 10 KHz and orchestral music, all presented at 80 dB (linear weighted), were also shown to emerge above the residual uterine sound. Attenuation of external sound was observed to vary as a function of frequency, with less attenuation of lower frequencies. It was determined that the music

was transmitted into the uterus without sufficient distortion to significantly alter the recognisable characteristics of the music.

7.2 INTRODUCTION

Several acoustic recordings of the intrauterine environment have been documented. Walker et al (1971) inserted a microphone, covered by a rubber sleeve, through the cervix to a position close to the fetal ear. A mean basal noise level of 85 dB re 20 μ Pa (linear weighted) was recorded, with peaks of 95 dB occurring simultaneously with maternal pulse (appendix 1.1). Attenuation of external sounds was shown to range from 30 to 40 dB for sound between 50 Hz and 1000 Hz, to 60 dB at 3000 Hz. It was concluded that external noises were mostly masked by the background intrauterine sound. Using a hydrophone, Querleu et al. (1981) calibrated intrauterine sound levels in three women in active labour, after the rupture of membranes. A predominantly low frequency basal noise was measured at an average of 89 dB re 20 μ Pa, linear weighted in a 16 KHz band. This figure converts to 65 dB on the A-weighted scale which corresponds more accurately with human hearing abilities. External white noise was shown to penetrate the uterus with attenuation varying as a function of frequency, with 2 dB (linear weighted) attenuation at 250 Hz, 14 dB at 500 Hz, 20,4 dB at 1000 Hz and 26 dB at 2000 Hz. The maternal voice, as well as external female and male voices was shown to emerge above the uterine sounds. Benzaquen et al. (1990) measured intrauterine sound levels by placing a hydrophone at the level of the fetal neck, after rupture of membranes. Low frequency sound pressure levels (less than 100 Hz) were determined up to 85 dB re 20 Pa (linear weighted), with maternal bowel sounds and vocalisations emerging above background sounds. Using a microphone, covered with latex and an elastic band, Smith et al. (1990) tested 9 subjects after rupture of membranes. Baseline intrauterine sound pressure levels ranged between 72 dB and 88 dB (assumed to be linear weighted and referenced to 20 μ Pa).

The author's study was conducted in order to determine the transmission of music into the intrauterine acoustic environment and to compare the characteristics of the music presented externally with the music recorded

internally. Presentations of the human singing voice (maternal and external male and female voices), and of recorded instrumental music, were made in order to provide an indication of the range of musical sounds which are able to penetrate the uterus. Analysis of the recordings was conducted in order to confirm the few published descriptions of natural intrauterine sounds (including intensity levels and frequencies); to determine the emergence of external sounds above them; the attenuation, as a function of frequency, which occurs when external sounds penetrate the uterus; and the quality of musical sounds which emerge above the uterine sounds.

The acoustic stimulation test (AST) has become a widely-used means of determining fetal well-being (Romero et al. 1988). It requires a shorter testing period than the more commonly used non stress test (NST), and reduces the number of non-reactive tests (Smith et al. 1986) and equivocal tests (Davey et al. 1984). The results of this study provide valuable information in the practice of fetal acoustic stimulation, regarding the effects of maternal mass, rupture of membranes and the presence of contractions, on the intrauterine sound pressure levels. The study provides an indication of the sound pressure levels to which the fetus may be subjected during such acoustic stimulation practices.

7.3 MATERIALS AND METHODS

7.3.1 Subject selection

Eight women admitted to the New Somerset Hospital, in early labour, with cervical dilation of at least one centimeter, were selected for testing. Four subjects had intact membranes and four had ruptured membranes. Written maternal consent prior to commencement of procedures was obtained. Exclusion criteria included maternal and fetal complications such as maternal hypertension, prolonged rupture of membranes, maternal pyrexia, fetal distress and premature or postmature labour. All fetuses were in cephalic presentation and gestational ages were from 38 to 41 weeks.

7.3.2 Equipment

Equipment required for the recording of intrauterine sound included a Brüel and Kjaer type 8103 hydrophone, the external dimensions being 50 mm in length and 9.5 mm in diameter (fig 7.1). The frequency range of the hydrophone is from 0.1 Hz to 200 KHz, with a nominal sensitivity of -211 dB (Ref 1V/ μ Pa). The hydrophone has a flat frequency response from 0.1 Hz to 80 KHz (further data regarding the equipment may be found in the appendix). A plastic tube, 15 cm in length and 1 cm in diameter was used as an introducer for the hydrophone, so as to avoid contact with organisms in the vagina. The hydrophone was connected to a Brüel and Kjaer type 2635 charge amplifier and a Kröhn-Hite filter model 3202 (fig 7.2).



FIG 7.1. The Brüel and Kjaer hydrophone type 8103.



FIG 7.2. The Brüel and Kjaer type 2635 charge amplifier and a Kröhn-Hite filter model 3202.

The intrauterine and external recordings were conducted by means of a TEAC DAT tape recorder model RD-101T, bandlimited to the 0 Hz - 10 KHz frequency range (fig 7.4). The Brüel and Kjaer type 2215 sound level meter was used to record the external sound and to determine sound pressure levels levels of the acoustic stimuli (fig 7.3). All sound pressure levels of external stimuli were measured .5 meters away from the maternal abdomen, at a position equidistant from the speakers to the hydrophone.



FIG 7.3. The Brüel and Kjaer type 2215 sound level meter.

The pure tone and music stimuli were presented through a Bang and Olufsen speaker BEOVOX S45, attached to a TEAC audio amplifier model AS-M30 (fig 7.4).

The music stimulus, which was prerecorded onto audio cassette, was delivered by a DENON cassette tape deck model DR-MO7 (fig 7.4). Three pure tone sweeps (50 Hz - 100 Hz; 100 Hz- 1000 Hz; 1000 Hz - 2000 Hz) were delivered by a Hewlett Packard synthesizer/function generator model 3325A (fig 7.5) at an average sound pressure level of 80 dB as indicated on the linear weighted sound level meter. The music excerpt was the first 60 seconds of the Brandenburg Concerto No. 1 BWV 1046, by J.S. Bach. The frequencies ranged between 15 Hz and 10 KHz, and the sound pressure level was an average of 80 dB, as indicated on the linear weighted sound level meter.



FIG 7.4. The TEAC DAT tape recorder model RD-101T, Bang and Olufsen speaker BEOVOX S45, TEAC audio amplifier model AS-M30 and DENON cassette tape deck model DR-MO7

The maternal voice and external female and male voices were presented at a sound pressure level of approximately 60 dB, as indicated on the linear weighted sound level meter. Spectral analysis of the recordings was conducted by means of a Hewlett Packard spectrum analyser model 3582A, controlled by a Hewlett Packard computer model 9816. Graphs were plotted by means of a Hewlett Packard plotter, model 7475A. Time domain wave forms and narrowband spectra computed during and between heart beats were conducted using the Hewlett Packard 35665 spectrum analyser, linked to a Hewlett Packard Thinkjet printer using the Quatro Pro package.



FIG 7.5. The Hewlett Packard synthesizer/function generator model 3325A.

Calibration of the hydrophone and the sound level meter was achieved by means of a Brüel and Kjaer Type 4223 and type 4220 calibrator, respectively.

7.3.3 Procedure

The facilities used were those of the Maternity Ward of the New Somerset Hospital. Approval of the Ethics and Research Committee of the University of Cape Town was obtained. Permission for the study was obtained from the Superintendent of the Somerset Hospital.

Suitable patients were selected and maternal consent obtained prior to testing. The hydrophone and a metre of its cord, as well as the plastic introducing tube, were sterilised in Vircon and thereafter rinsed in a dilute solution of iodine in water. During the course of a routine vaginal examination, the tube was inserted into the vagina. The hydrophone was introduced through the tube and then inserted through the cervix, 10 cm to 15 cm beyond the cervical os, next to the fetal head. Chlorhexidine obstetric cream was used as a lubricant during introduction of the hydrophone. The tube was then removed to a position just outside the vagina and strapped to the cord of the hydrophone. After the examination was complete, the investigator and acoustic engineer entered the labour ward with the pre-assembled equipment on a trolley, which was positioned one metre away from the maternal abdomen. The cord of the hydrophone was attached to the amplifier and the sound level meter was clamped to a tripod, at a half-metre horizontal distance from the mother's abdomen, at a position equidistant from the speaker to the internally-inserted hydrophone. Recording began immediately, with a 2-minute period of no external acoustic stimulation, followed by presentation of the three pure tone sweeps, each lasting 90 sec (fig 7.6). Thereafter the music recording, the maternal voice, and external male and female voices were each presented for about 60 sec. After completion of the procedure, the hydrophone was disconnected from the amplifier, and

the investigator and engineer vacated the labour ward, removing the trolley. The hydrophone was removed by the Obstetrician during the subsequent vaginal examination. Spectral analysis of the recordings took place in a laboratory.



FIG 7.6. *The setting for the intrauterine acoustic recording procedure.*

7.4 RESULTS

The intrauterine acoustic environment was determined to consist of a predominantly low-frequency background noise, with intermittent emergence of other sounds (assumed to be cardiovascular and intestinal sounds). The

average baseline uterine sound pressure level (SPL) of the 8 subjects (measured between 20 Hz and 10 KHz and averaged over 32 seconds) was 90 dB re 20 μ Pa in a 10 KHz band (linear weighted) within the limits of 76 dB and 92 dB (figs 7.7, 7.9). However, on the A-weighted scale (which corresponds more accurately with human hearing abilities by predominantly attenuating the lower frequency levels) this converts approximately to 66 dBA (A-weighted) (fig 7.8). An approximate 10 dB difference was determined between the intrauterine SPL analysed during and between heart beats (fig 7.10). Time domain wave forms of the residual intrauterine sound and the intrauterine sound during presentation of the music stimulus provide further information (figs 7.11, 7.12,7.13). At selected frequencies, the following SPLs were measured:

FREQUENCY	SOUND PRESSURE LEVEL (linear weighted) re 20 μ Pa
25 Hz	84 dB
80 Hz	70 dB
200 Hz	64 dB
500 Hz	63 dB
1000 Hz	53 dB

It was determined that pure tones from 50 Hz to 10 KHz (presented at 80 dB at a distance of 1 m from the subject) all emerge above background uterine sounds (figs 7.14, 7.15, 7.16). It was observed that there is less attenuation of lower frequencies (eg. about 10 dB at 400 Hz), with a steady increase in attenuation of frequencies between about 400 Hz and 1000 Hz, above which there is an average attenuation of 35 dB. The recorded excerpt of orchestral music (presented at 80 dB at a distance of 1 m from the subject) was determined to emerge above background uterine sounds (figs 7.17, 7.18, 7.19). Furthermore the external female voices and male voices, presented at a distance of 1 m from the subject, and the maternal voice (all presented at an average of 60 dB) emerge above the background uterine sound (figs 7.18,

7.20, 7.21, 7.22). Emergence of all the voices occurred predominantly between 200 Hz and 500 Hz. The highest point of emergence of voices generally occurred at about 200 Hz, with the emergence of a maternal voice occurring by an amount of 25 dB above the residual intrauterine sound pressure level, an external female voice by 15 dB and a male voice by 15 dB.

7.5 DISCUSSION

At no time during the procedure did any subject report pain as a result of the placement or presence of the hydrophone. All eight women had a normal labour and subsequent uncomplicated delivery. There were no side effects resulting from the investigation, with no infection or fever occurring.

The recording system filtered out frequencies below 25 Hz to which the human ear is less sensitive but which would have saturated the equipment. Frequencies above 1000 Hz may not be representative, due to the high level of equipment noise experienced in this band (fig 38). The graph of the equipment noise indicates a peak at 50 Hz, corresponding to interference from the electricity main supply. Narrow band analysis was conducted of pure tone stimuli, while other graphs are represented in third-octave bandwidths, with or without bandwidth correction.

The average measurement of the residual intrauterine SPL in eight subjects, measured at 90 dB, confirms the measurement of 89 dB determined by Querleu et al. (1981). It is to be noted that this is recorded using linear weighting. The A-weighted scale is used in this study because it corresponds more closely with human hearing abilities by progressively reducing the levels of the lower frequencies. Much of the sound in the uterine environment is caused by low-frequency sounds, to which the human ear is less sensitive. The average intrauterine sound pressure level of 90 dB (linear weighted) converts to 66 dBA (A-weighted) (appendix 1.2).

A similar residual acoustic environment was determined in all subjects, apart from differences occurring in the presence and amplitude of cardiovascular and intestinal sounds, the former difference being attributed to the proximity of the hydrophone to major arteries. The position of the hydrophone was

assumed to vary slightly between subjects (due to the exact placement of the hydrophone) and at different stages of the test (possibly due to contractions and movements of the mother and the fetus). The slight differences in the graphs of the intrauterine sounds before and during the presentation of acoustic stimuli, which are outside of the frequency ranges of those stimuli, indicate fluctuations in the uterine acoustic environment.

Richards et al. (1991) determined that increasing depth of the hydrophone, in the uterus of a ewe, corresponds with a drop in sound pressure level. During presentation of an external auditory stimulus, sound pressure levels dropped from 119 dB to 102 dB, measured at depths of 5 cm and 20 cm). It is therefore assumed that the greatest possible degree of attenuation of external sound into the uterus of each subject was measured by placing the hydrophone in a posterior position.

No significant differences were observed in the intrauterine acoustic environments or in the attenuation of external sounds with regard to the rupture of membranes. Contrary to expectations, there were no consistent differences in residual sound pressure levels or in the attenuation of external sounds associated with differences in maternal mass, which ranged between subjects from 59 Kg to 100 Kg. The presence of contractions did not affect the recordings, apart from two cases when contractions became stronger during the test and the sound level during those contractions caused overloading of the recording system (possibly due to the friction of movement of the hydrophone). In these cases, acoustic stimuli were presented between contractions.

The high SPL of the intrauterine environment seems to indicate that most external sounds would be masked in the uterus. However, the highest levels occur in the low frequency region of the spectrum. The auditory threshold of the human requires a far greater SPL at lower frequencies in order to achieve equal loudness perception with higher frequencies (appendix 1.2). Spectral analysis of the recordings indicates the different frequency levels at which emergence above residual uterine sounds occurs. External sounds which, after transmission into the uterus, have similar or even lower sound pressure

levels to those of the intrauterine sounds, may emerge clearly as a result of their differing texture (ie. quality or tone colour). It was determined that a greater emergence occurs of the maternal voice than of external voices. This can be explained by the transmission of sounds directly through the body, in the case of the maternal voice. The coupling of external voices from the air to the abdomen involves impedance mismatch. The higher frequencies are attenuated to a greater extent, causing consonants to be indistinguishable. However, the timbre of the voice, the vowel sounds, the melodic rise and fall of the voice, and speech rhythms are not noticeably affected. The sound energy of speech occurs predominantly at about 500 Hz, which is the approximate frequency level of the first formant of vowel sounds. The spectral content of the voice shown on the graphs to emerge above the residual intrauterine sounds includes frequencies between approximately 200 Hz and 500 Hz, indicating the quality and texture of the voice emerging in the uterus and the emergence of vowel sounds. The instrumental music was not sufficiently distorted during the process of penetration into the uterus to cause a significant change in the character of the music. The greater attenuation of higher frequencies affects the articulation (attack) of notes, causing a slight muffling effect. The pulses, rhythms, melodies, harmonies, timbres of different instruments, changes in sound pressure levels and the balance of the sound pressure levels between different instruments (eg. violoncello and violin) are not noticeably affected.

The well-known Tomatis method of rehabilitation is based on a theory that the fetus hears predominantly the high frequencies of external sounds and it strives to recreate aspects of fetal sound environment in the rehabilitation of patients (Tomatis 1981). Patients are exposed to high-filtered recordings of the maternal voice (when available) and of music by Mozart. Although it is evident that the method has achieved considerable success, the author challenges the theory that the fetus is exposed to only the higher frequencies of external sounds. Intrauterine recordings made in this study determine that the character of music (rhythms, melodies, harmonies, textures, balance of sound pressure levels of the instruments etc.) is not significantly altered during transmission into the uterus. For example, the low frequencies of the violoncello are as clearly audible as those of the violin. Similarly, the maternal and other voices (male and female) are altered only to the degree that the

consonants become indistinguishable, while the character of the voices (timbre) is not noticeably changed.

While this study provides indication of the intrauterine acoustic environment, it does not investigate the fetal hearing process. Various theories have been proposed regarding the fluid in the fetal ear causing dampening of the response of the tympanic membrane and the ossicles, thus preventing the middle ear from impedance matching (Gagnon et al. 1986b). The study by Arulkumaran et al. (1992), addresses issues involved in the process of fetal hearing of externally-presented sounds. It was stated that the fluid in the fetal middle ear represents a situation similar to the fluid filling which occurs in effusive otitis media, causing a hearing loss of 20 dB. However, the author suggests that uterine sounds (consisting of the residual uterine sounds as well as external sounds which have been transmitted into the uterus) are well-coupled to the fluid environment of the cochlea. Thus, any hindrance to the impedance matching process may be irrelevant, as the pressure of the sound need not be increased at the cochlear wall (as is the case when the external auditory canal is filled with air). Furthermore the process of bone conduction should be taken into account, as the sound would also be transmitted through the fluid which surrounds the fetal head. The question of fetal hearing is not resolved in the literature.

The author suggests that the present study contributes to the knowledge of the acoustic environment of the fetus by determining the emergence of external pure tones above residual intrauterine sounds and the character of vocal and instrumental music which has been transmitted into the uterus.

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AVERAGE OF 8 SUBJECTS: RESIDUAL INTRAUTERINE SOUND PRESSURE LEVELS

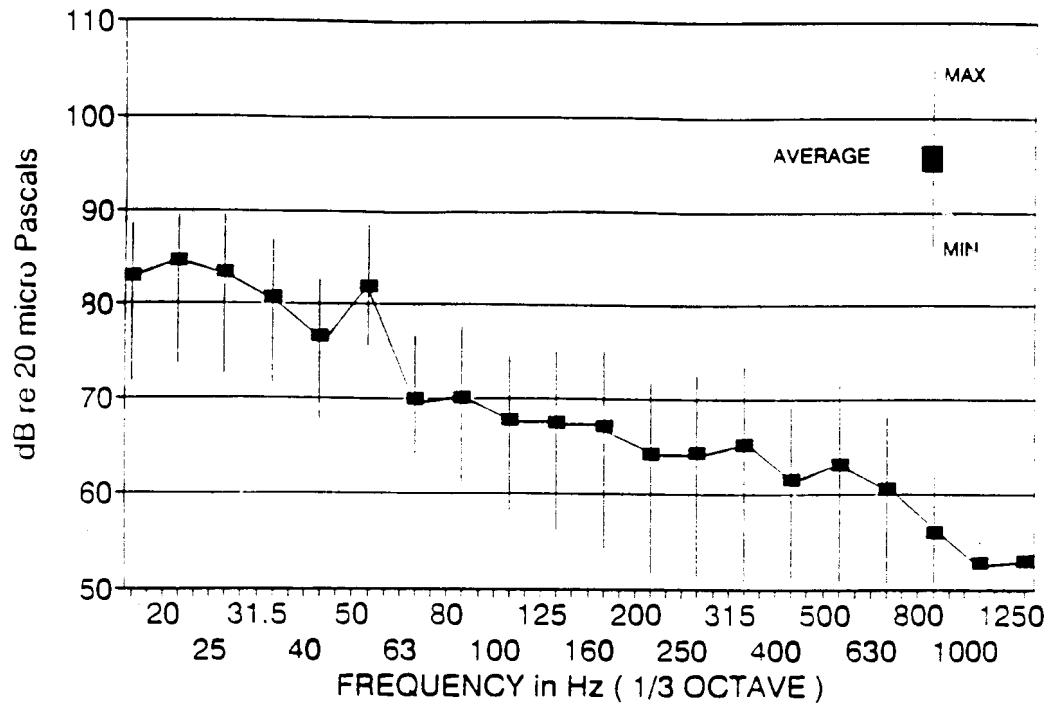


FIG 7.7. The average residual intrauterine SPL of 8 subjects with maximum and minimum variation (linear weighted, third-octave analysis, averaged over 32 seconds).

AVERAGE OF 8 SUBJECTS: RESIDUAL INTRAUTERINE SOUND PRESSURE LEVELS

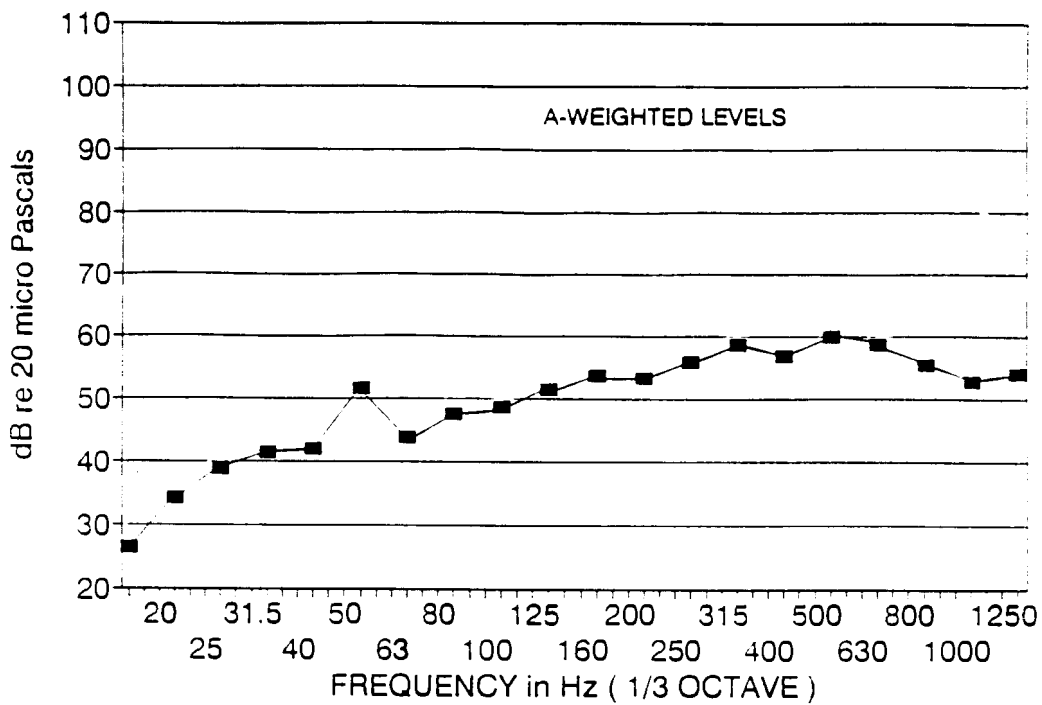


FIG 7.8. The average residual intrauterine SPL of 8 subjects (A-weighted, third-octave analysis, averaged over 32 seconds).

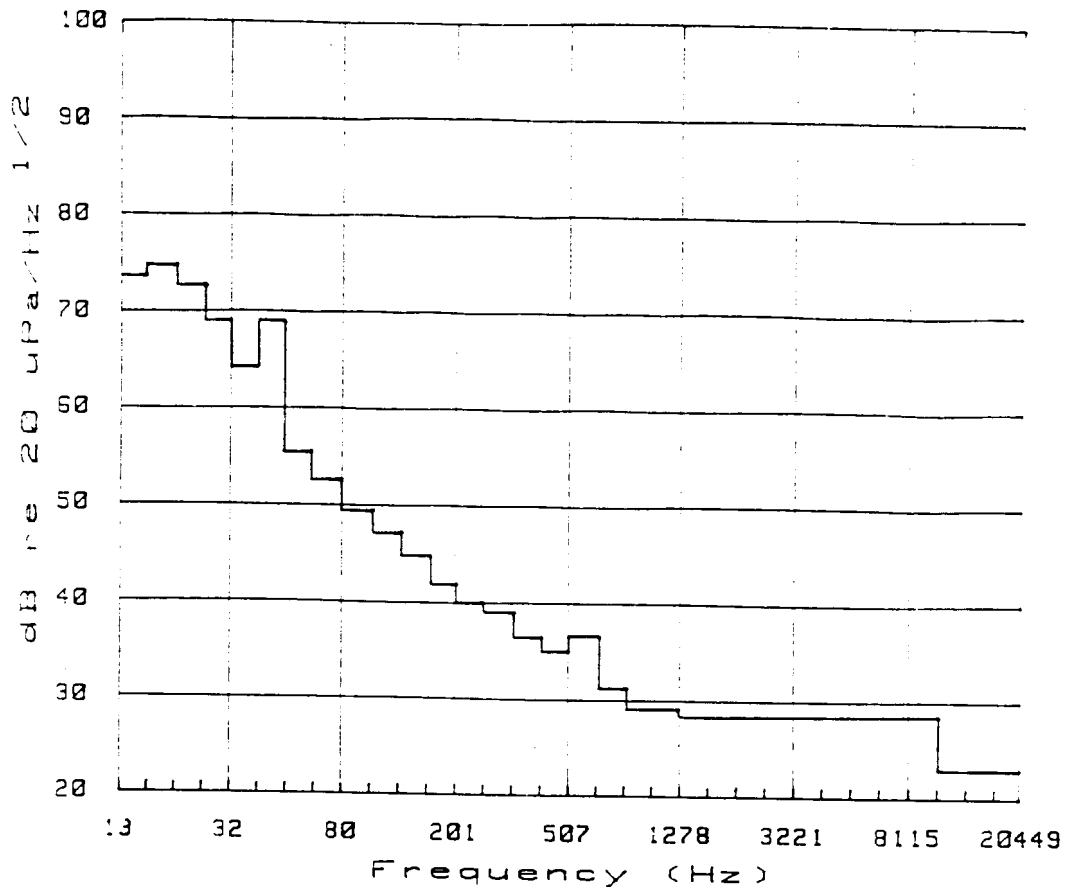


FIG 7.9. The average residual intrauterine SPL of 8 subjects (linear weighted, third-octave analysis, averaged over 32 seconds, bandwidth corrected).

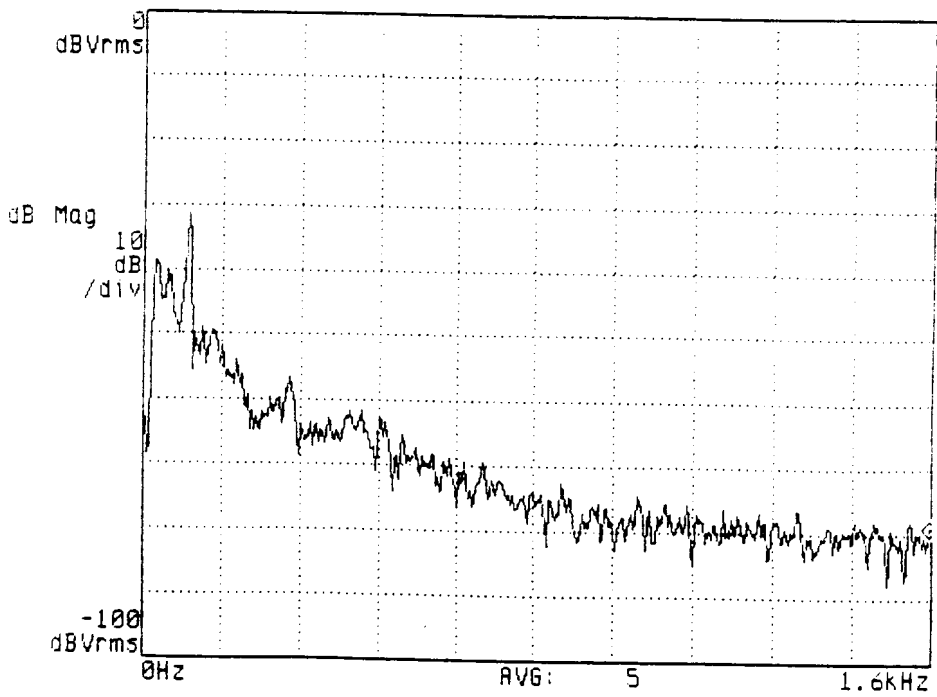
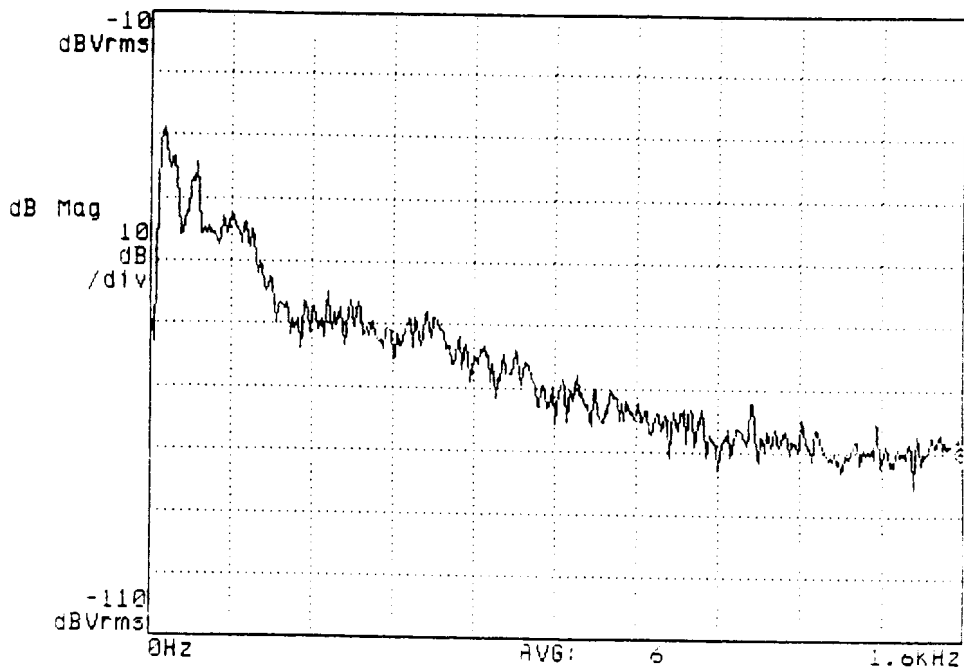


FIG 7.10. A. The spectral content of the intrauterine sound during a heart beat, with the presentation of an 88 Hz pure tone (average of 5 narrowband spectra, uncalibrated). B. The spectral content of the intrauterine sound between two heart beats, during presentation of an 88 Hz pure tone (average of 6 narrowband spectra, uncalibrated).

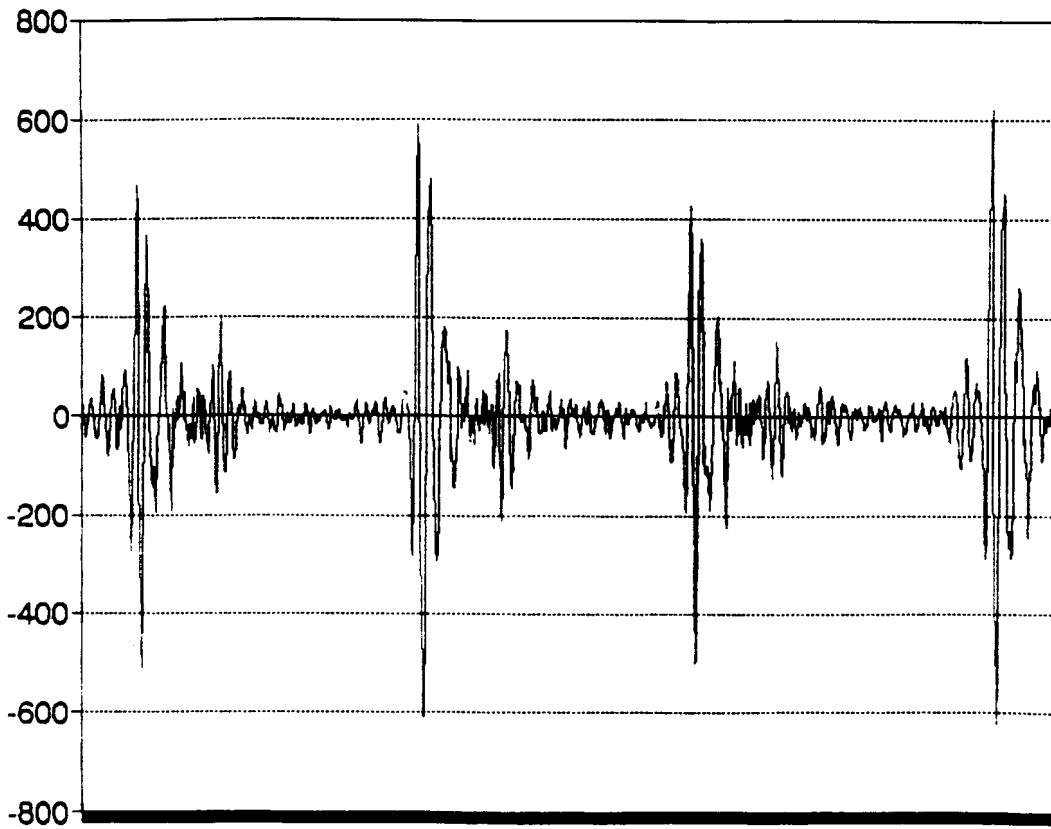


FIG 7.11. *The time domain wave form of the residual intrauterine sound over approximately 3 sec.*

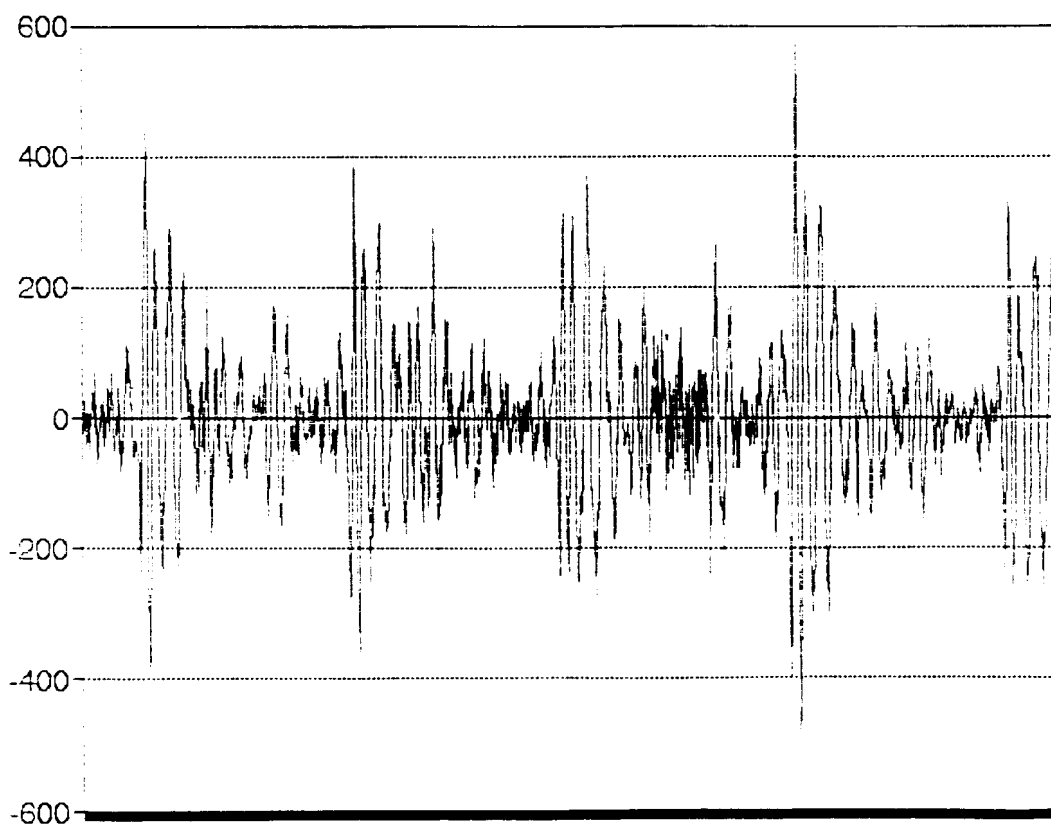


FIG 7.12. *The time domain wave form of the intrauterine sound during presentation of the music stimulus over approximately 3 sec.*

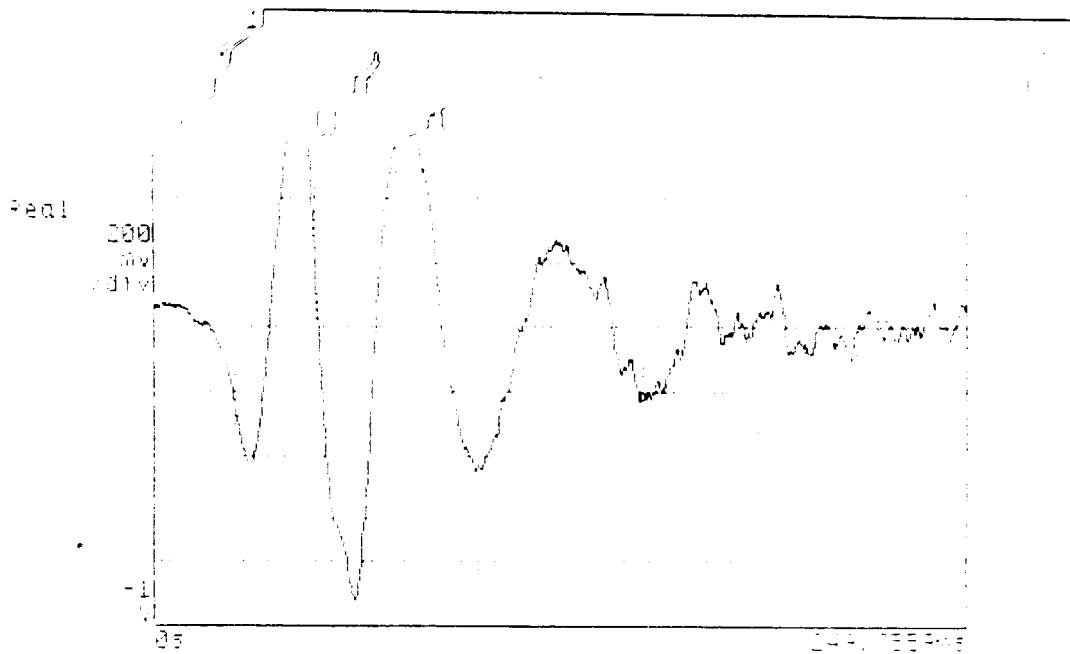


FIG 7.13. *The time domain wave form of a 250 ms portion of a heart beat.*

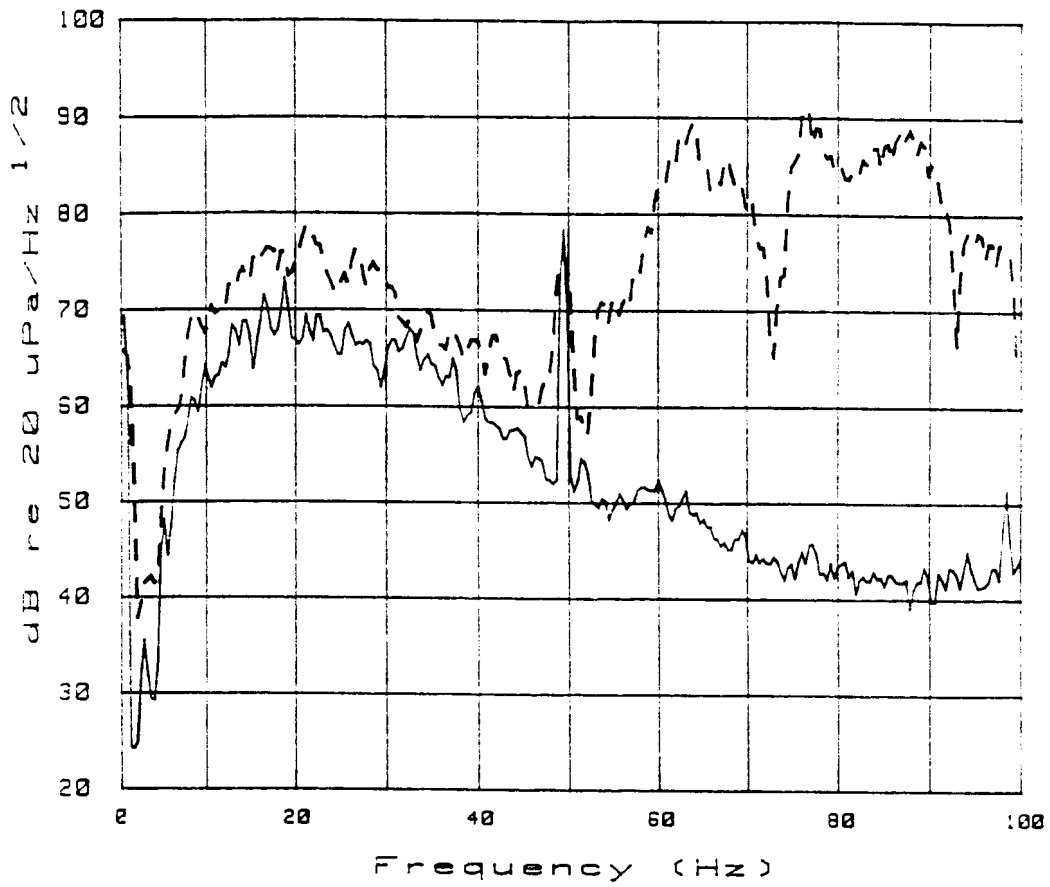


FIG 7.14. The residual intrauterine SPL of 1 subject (solid line) presented with the intrauterine SPL during presentation of the pure tone sweep from 50 Hz to 100 Hz (broken line) (linear weighted, narrow band analysis).

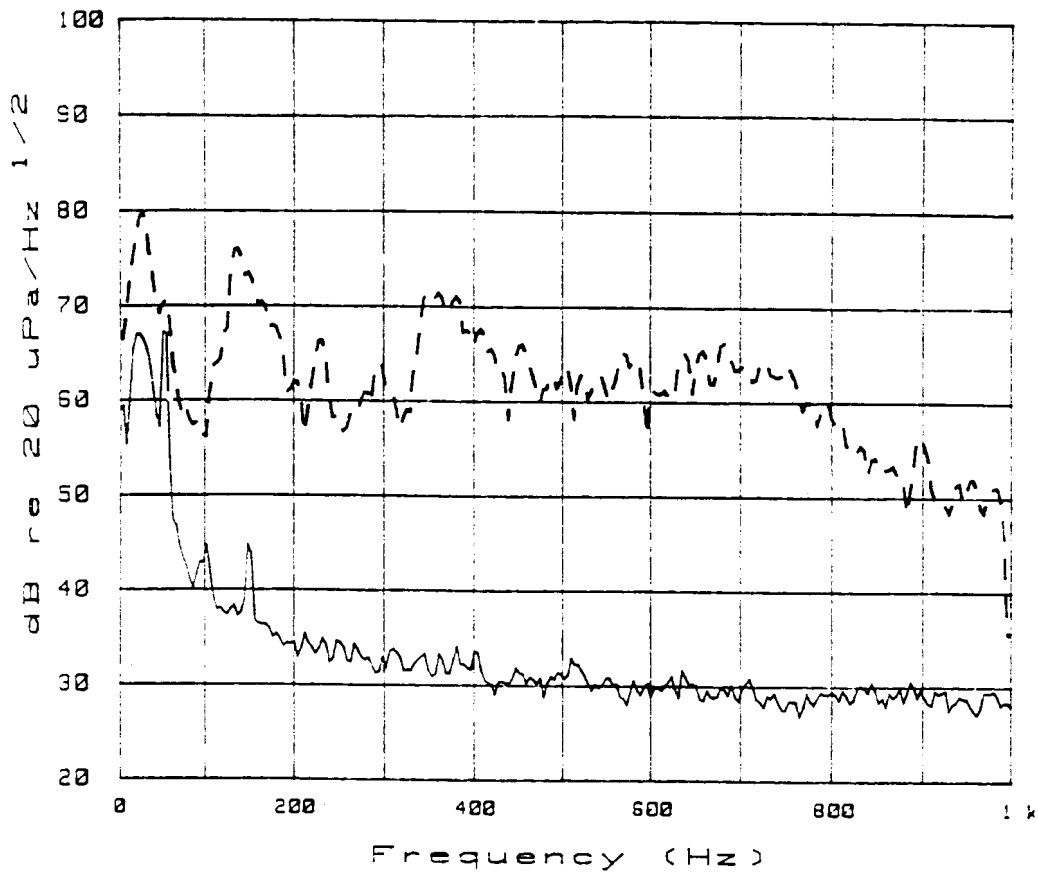


FIG 7.15. The residual intrauterine SPL of 1 subject (solid line) presented with the intrauterine SPL during presentation of the pure tone sweep from 100 Hz to 1 KHz (broken line) (linear weighted, narrow band analysis).

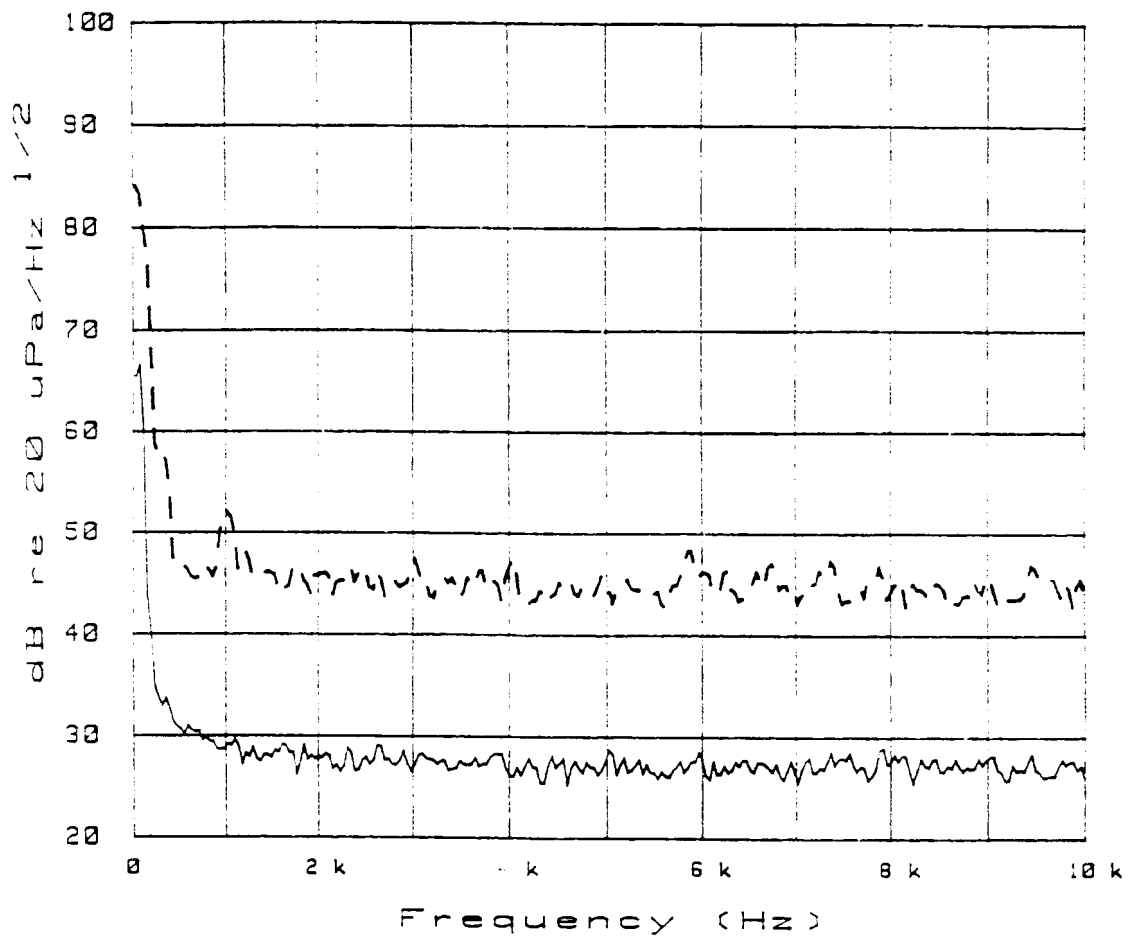


FIG 7.16. The residual intraurine SPL of 1 subject (solid line) presented with the intraurine SPL during presentation of the pure tone sweep from 1 KHz to 10 KHz (broken line) (linear weighted, narrow band analysis).

AVERAGE OF 8 SUBJECTS: INTRAUTERINE SOUND PRESSURE LEVELS + MUSIC STIMULI

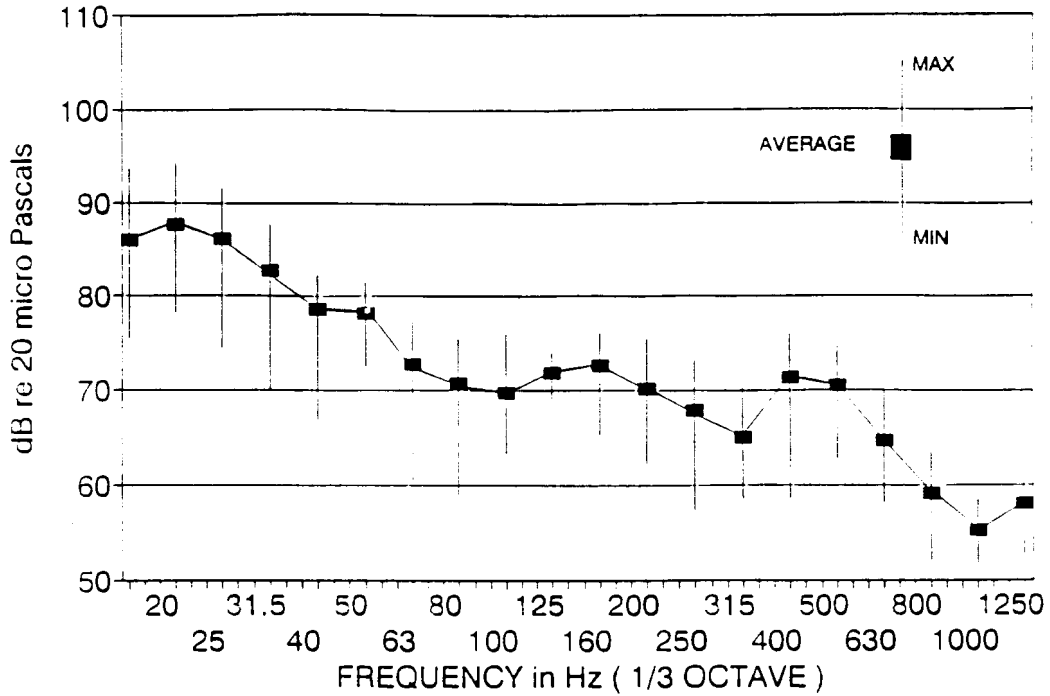


FIG 7.17. *The average intrauterine SPL of 8 subjects during presentation of the music stimulus with maximum and minimum variation (linear weighted, third-octave analysis, averaged over 32 seconds).*

AVERAGE OF 8 SUBJECTS: INTRAUTERINE SOUND PRESSURE LEVELS + MUSIC STIMULI

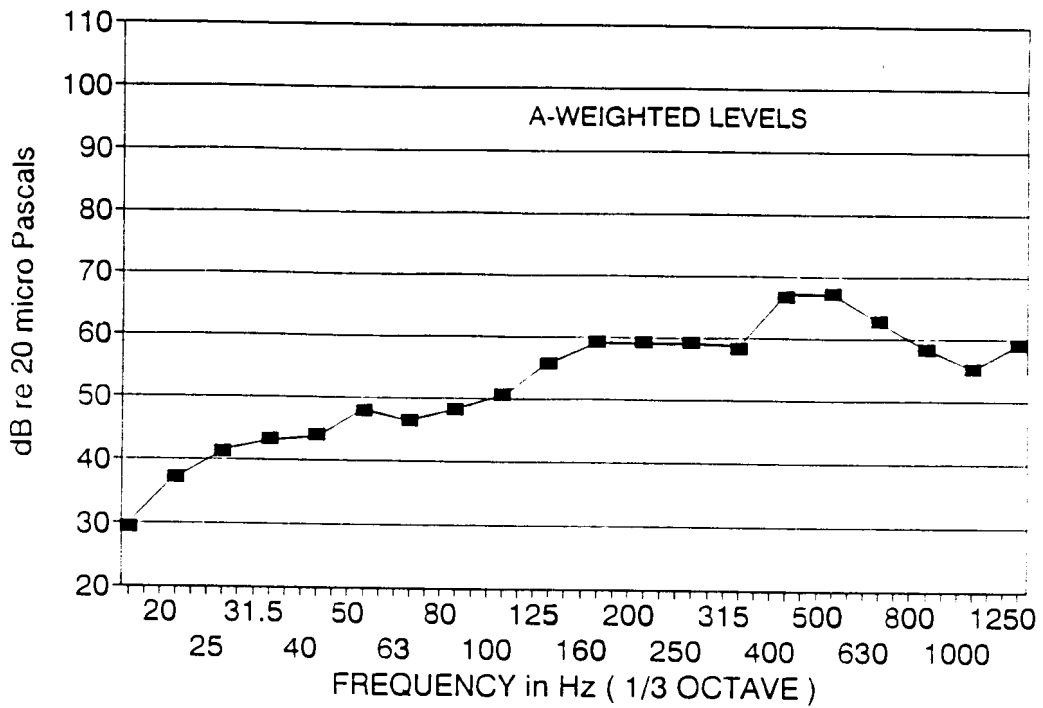


FIG 7.18. The average intrauterine SPL of 8 subjects during presentation of the music stimulus (A-weighted, third-octave analysis, averaged over 32 seconds).

AVERAGE OF 8 SUBJECTS: RESIDUAL VERSUS MUSIC SOUND PRESSURE LEVELS

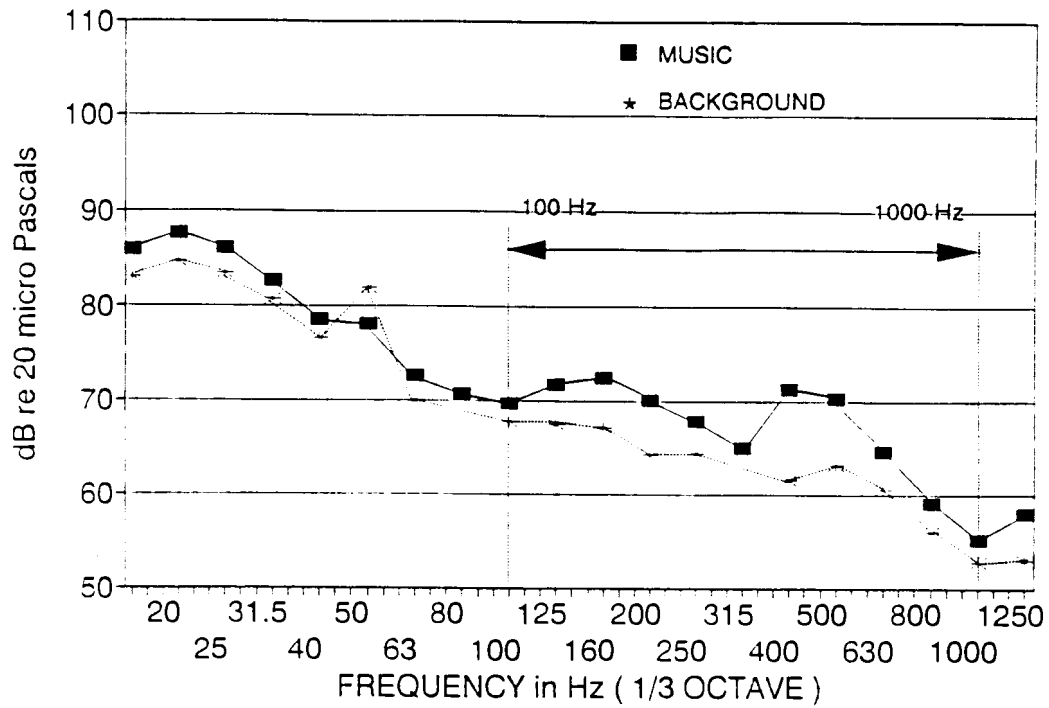


FIG 7.19. The average residual intrauterine SPL of 8 subjects (broken line) with the average intrauterine SPL of 8 subjects during presentation of the music stimulus (solid line) (linear weighted, third-octave analysis, averaged over 32 seconds).

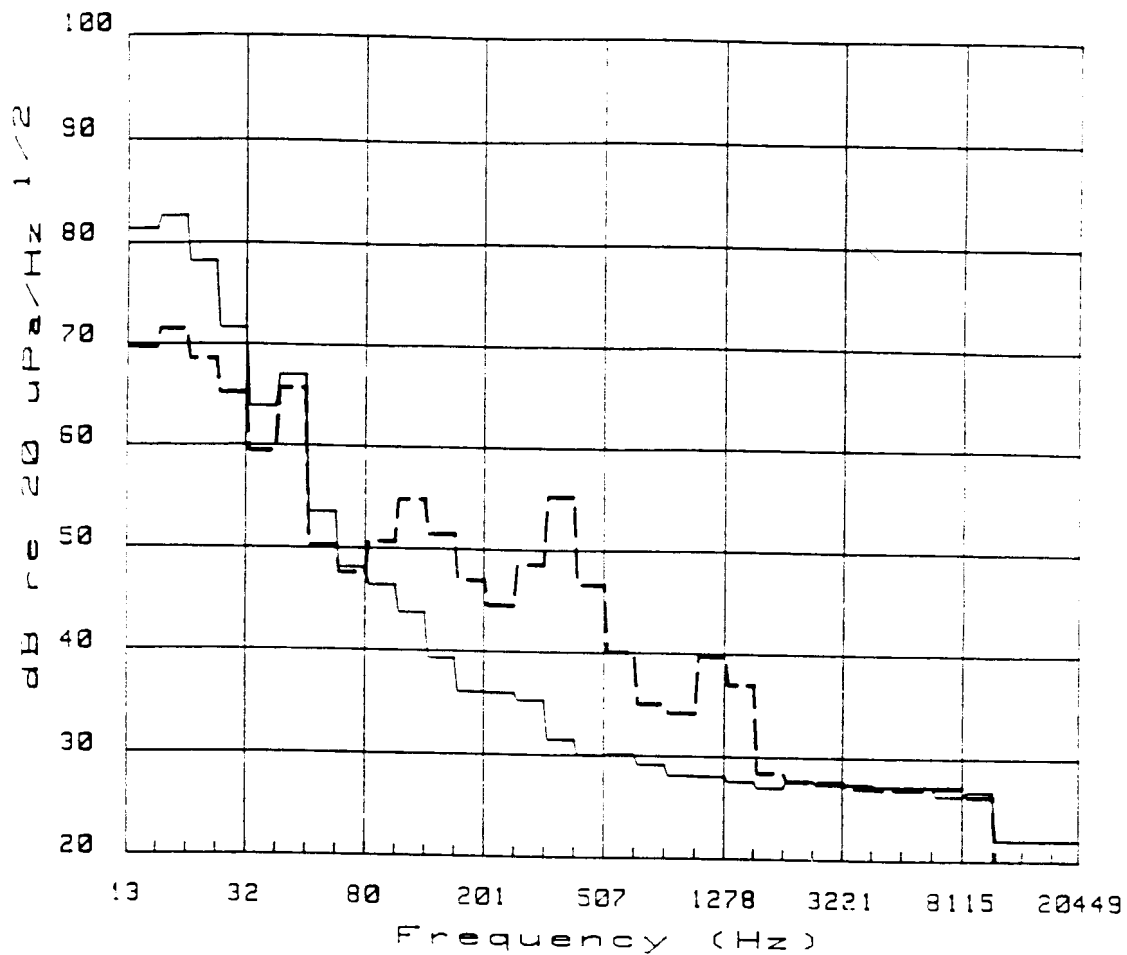


FIG 7.20 The average residual intrauterine SPL of 8 subjects (solid) with the average intrauterine SPL of 8 subjects during presentation of the music stimulus (broken line) (linear weighted, third-octave analysis, averaged over 32 seconds, bandwidth corrected).

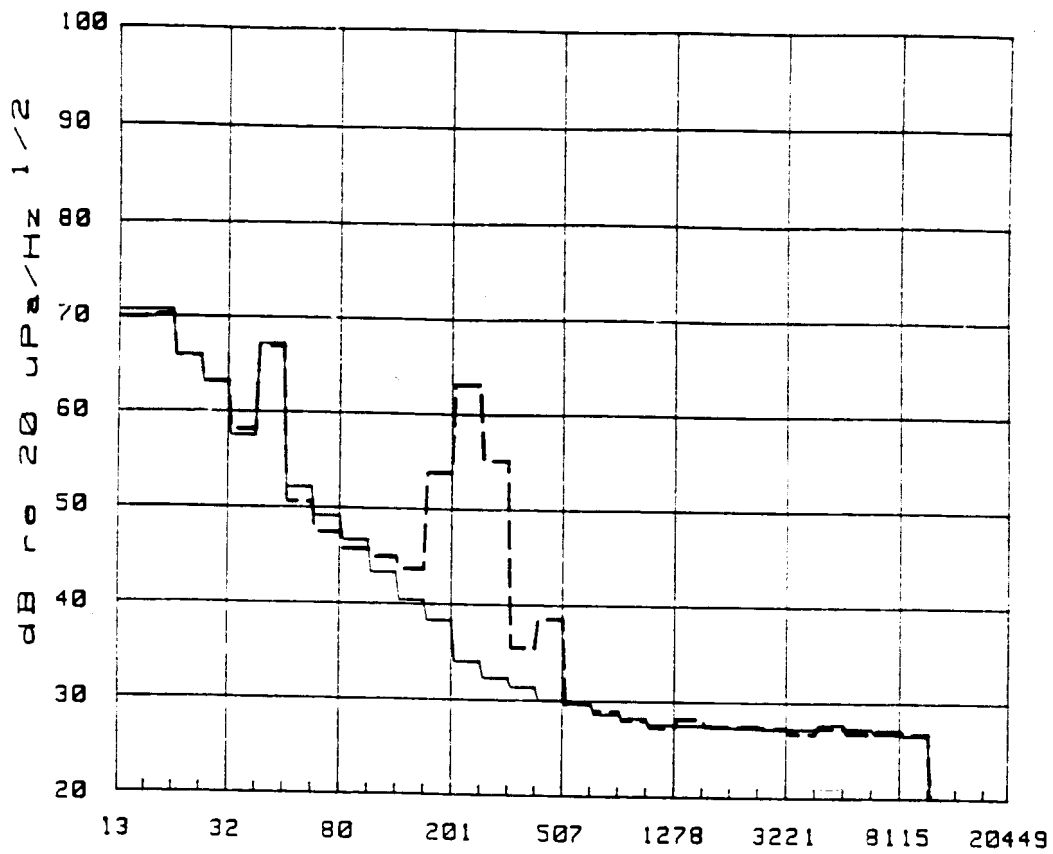


FIG 7.21. *The residual intrauterine SPL of 1 subject (solid line) with the intrauterine SPL during presentation of the maternal voice (broken line) (linear weighted, third-octave analysis, averaged over 32 seconds, bandwidth corrected).*

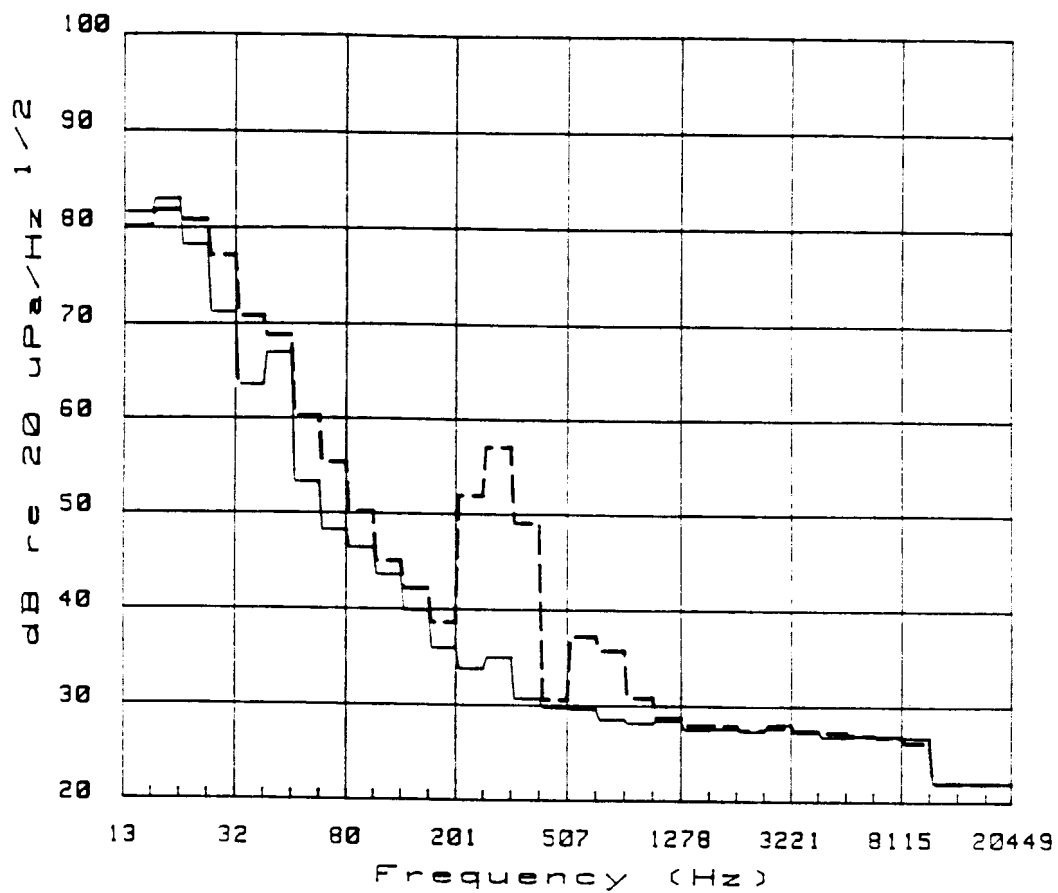


FIG 7.22. The residual intrauterine SPL of 1 subject (solid line) presented with the intrauterine SPL during presentation of the external female voice (broken line) (linear weighted, third-octave analysis, averaged over 32 seconds, bandwidth corrected).

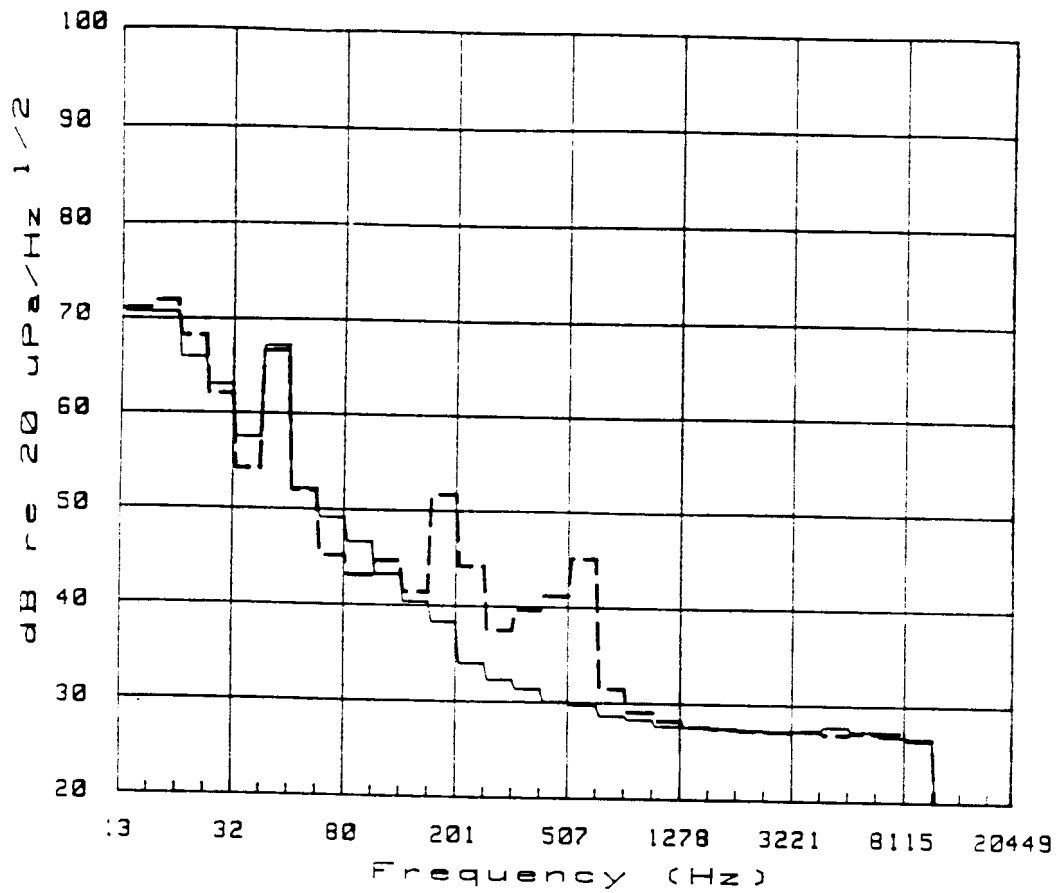


FIG 7.23. The residual intrauterine SPL of 1 subject (solid line) presented with the intrauterine SPL during presentation of the male voice (broken line) (linear weighted, third-octave analysis, averaged over 32 seconds, bandwidth corrected).



"MY Heart's a-pounding..."

FETAL HEART RATE RESPONSE TO A MUSIC STIMULUS.

8.1 ABSTRACT

The fetal heart rate (FHR) response to a music stimulus (MS) and a vibroacoustic stimulus (VS) was measured in 40 subjects. Gestational age of the fetuses ranged from 32 to 42 weeks. The study included a control period with no acoustic stimulation; a period with the presentation of 5 music stimuli; and a period with the presentation of 5 vibroacoustic stimuli. A change in the FHR of 15 beats per minute or greater, lasting 15 seconds and occurring within 15 seconds of at least 2 of the 5 stimuli (or a tachycardia of greater than 15 beats per minute above the resting baseline, sustained for one minute or longer) was considered to be a positive response. The MS elicited a positive response in 35 of the fetuses (the 5 non-responses occurring in a period of low FHR variability) and all 40 fetuses responded to the VS (regardless of arousal state).

8.2 INTRODUCTION

Maternal perception of fetal movement response to sounds, has led to intensive studies of fetal response to acoustic stimulation (AS). From 1925, investigations have indicated a fetal 'startle' response to loud sounds (Peiper 1925). Since then, fetal response to pure tone or high-pass filtered (ie. the low frequencies having been excluded) acoustic stimuli has been well documented (Johansson et al. 1964, Grimwade et al. 1971, Jensen and Flottorp 1982).

These responses are shown to be independent of maternal response (Grimwade et al. 1971, Lecanuet et al. 1986).

Ultrasound imaging has facilitated the detection of facial, head, hand, limb and trunk movements, auro-palpebral response and fetal breathing movements associated with AS (Gelman et al. 1982, Lecanuet et al. 1986). The fetal heart rate (FHR) response to AS has been observed using cardiotocography (Read et al. 1977, Trudinger and Boylan 1980, Jensen 1984, Marin et al. 1987). The consistency of the FHR response to AS during the third trimester of pregnancy has led to its use as a means of fetal surveillance (Read and Miller 1977, Serafini et al. 1984, Romero et al. 1988). Compared with the more commonly used non stress test, the acoustic stimulation test is shown to reduce testing time, the number of non-reactive tests and the number of equivocal tests (Smith et al. 1986, Davey et al. 1984).

The fetal response has been shown to be influenced by a variety of factors, including gestational age, the state of neurological arousal and the type of stimulus. Functional maturity of the fetal auditory system is indicated by the structural maturity of the human ear attained by the 24th week of gestation, the activity of the eighth cranial nerve at this stage, and the detection of cortical potentials and auditory brain stem potentials in the preterm neonate of 25 weeks (Anson and Donaldson 1973, Gerber 1977, Starr et al. 1977). Studies of pure tone acoustic stimulation have determined fetal response in the third trimester of pregnancy, with no response being elicited in the 6th month of pregnancy (Bernard and Sontag 1947, Murphy and Smyth 1962, Tanaka and Arayama 1969). While a fetal response to vibroacoustic stimulation has been observed as early as 22 weeks gestation, a consistent response has been determined from 28 weeks (Leader et al. 1982, Birnholz and Benacerraf 1983, Kuhlman et al. 1988). The presence of fetal behavioural states (states 1F, 2F, 3F, and 4F) has been described and defined by Nijhuis et al. (1982). More frequent responses to sounds above 300 Hz have been observed during 'awake' states (sometimes defined as episodes of high FHR variability) than during 'sleep' states (Schmidt et al. 1985, Lecanuet et al. 1986). In contrast, lower frequency vibroacoustic sound sources have been shown to elicit a fetal response regardless of the arousal state of the fetus (Leader et al. 1984). Acoustic and vibroacoustic stimulation, presented during

a period of low FHR variability, have been shown to be associated with a change in the FHR to a high variability pattern (Gelman et al. 1982, Gagnon et al. 1986a, Ohel et al. 1986a). Both the frequency and the intensity of the stimulus are shown to influence response (Murphy and Smyth 1962, Gelman et al. 1982). Varying response ratios to pure tones may, in some cases, be due to the attenuation of external sounds which occurs as a function of frequency (Querleu et al. 1981). Greater response has been elicited by a stimulus presented at 110 dB than at 105 dB, and by a stimulus delivered at 80 dB than at 70 dB (Kisilevsky et al. 1989, Lecanuet et al. 1986, Jensen 1984a).

The present study was undertaken to determine the FHR response of the normal third trimester fetus to a music stimulus (MS). This study also aimed to observe the effects of arousal state on the FHR response to music and to compare the response to that of vibroacoustic stimulation commonly used in the assessment of fetal well-being. The FHR response to varying time periods of music stimulation was also investigated.

8.3 METHODS AND MATERIALS

8.3.1 Subject Selection

Forty subjects undergoing non stress tests at the Johannesburg Hospital were selected for this test using an exclusion process. The gestational ages of the fetuses ranged between 32 and 42 weeks. Exclusion criteria included multiple pregnancies, medical conditions such as diabetes and hypertension, suspected intrauterine growth retardation and patients receiving medication which could affect the FHR. In all cases, the indication for non stress testing was maternal perception of decreased fetal movement. The fetal heart rate tracings were all determined to be reactive and there were no indications of pathology. Analysis of hospital records determined that all the neonates had normal birthweights and were classified as clinically normal. All fetuses were cephalic presentations. The mothers had eaten breakfast which was assessed as being of adequate calorie

intake. Testing took place over a three-week period between 08h30 and 11h00.

8.3.2 Materials

The MS was delivered by a Kenwood tape deck (Model KX660HX), linked to a Kenwood amplifier (Model KA 87), and presented via AKG headphones (Model K270) which were strapped to the mother's abdomen.

The prerecorded excerpt of music from the organ prelude by J.S. Bach BWV 548 was presented at 100 dB, delivering a frequency range of 15 Hz to 14000 Hz, with a predominance of frequencies between 80 Hz and 3000 Hz. Acoustic calibration was achieved by means of a Brüel and Kjaer frequency analyser, model 2131, linked to a Hewlett Packard computer, type 9836. The VS was delivered by a hand-held battery-powered fetal acoustic stimulator (Corometrics Medical Systems Inc. Model 146) (fig 8.1). This delivered sound with a frequency of 75 Hz +/- 10 % and harmonics ranging from 20 Hz to 900 Hz, at an intensity level of 74 dB measured at 1 m in the air. The FHR was continuously recorded by the use of the Hewlett Packard cardiocograph (models 8040A and 8041A) (fig 8.2). Paper speed was 3 cm/min.

8.3.3 Procedure

The research protocol was approved by the University of the Witwatersrand Committee for Research on Human Subjects. Patients admitted to the Johannesburg Hospital for routine non stress cardiocography were recruited for simultaneous acoustic stimulation testing. The tests were conducted with the consent of the mother, after she was informed of the procedures involved. Cardiocography was performed whilst the patient was in a semi-reclining lateral position, in order to exclude any arterial hypotension which may have affected fetal response. The transducer of the cardiocograph was placed on the

mother's abdomen, in the region of the fetal shoulder, for optimal FHR recording. The mother was provided with an event marker which she was instructed to press whenever fetal movements were felt. The headphones were strapped to the mother's abdomen in close proximity to the fetal head (fig 8.3). Acoustic stimuli were activated by the researcher and the onset of each stimulus was marked on the FHR tracing.



FIG 8.1. The fetal acoustic stimulator (Corometrics Medical Systems Inc. model 146).

The study included three 5-minute periods of testing: a control period with no AS, a period during which the music stimuli were presented and a period of vibroacoustic stimulation. The three periods were separated by 2-minute intervals, and their order was randomly selected for each test. During the music period the stimulus was presented at

the start of each minute, on four occasions for 15 seconds and once for a period of 60 seconds. The order of these presentations was randomly selected. During the vibroacoustic period, a 2-second stimulus was presented at the start of each minute. Testing took place regardless of low or high FHR variability patterns.

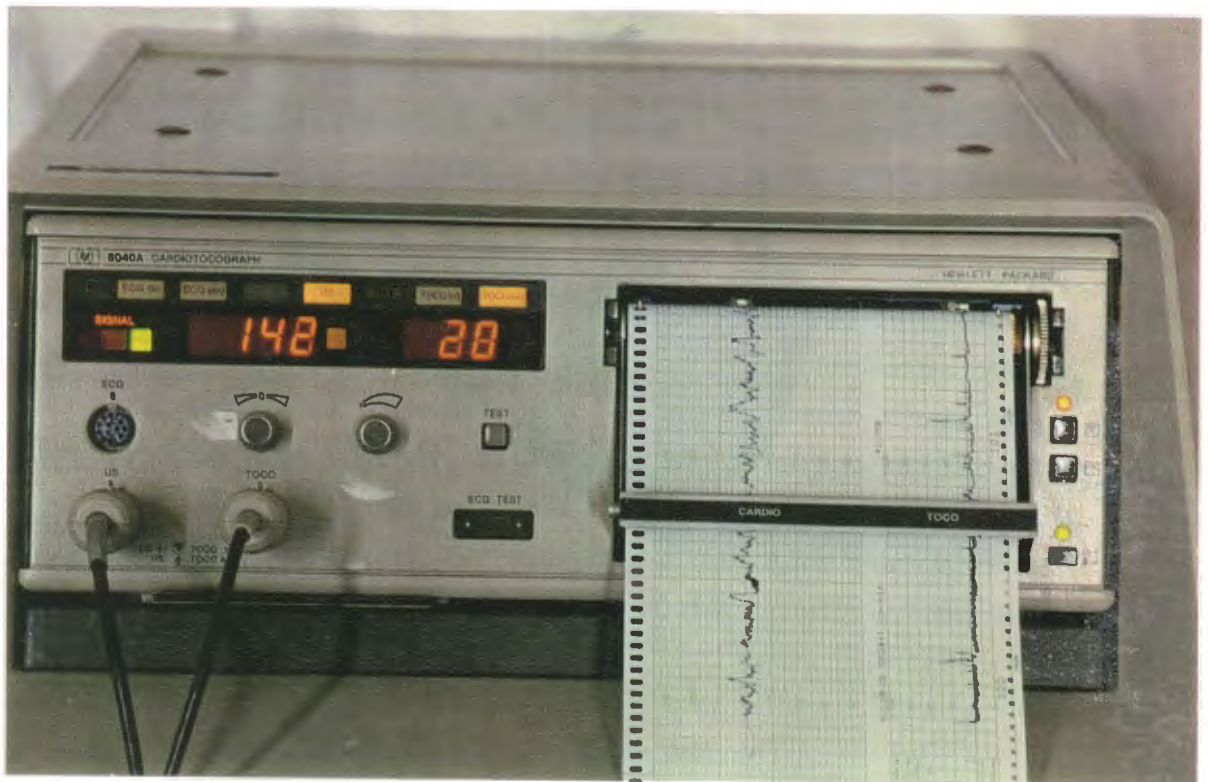


FIG 8.2. The Hewlett Packard cardiotocograph model 8040A



FIG 8.3. *Presentation of the music stimulus during recording of FHR.*

8.3.4 Data Analysis

The FHR tracings were interpreted by two investigators. An acceleration in the FHR of 15 beats per minute or greater, lasting for 15 seconds or longer and occurring within 15 seconds of at least 2 of the 5 stimuli was considered to be a positive response. The test was also considered reactive if a tachycardia (increase in fetal heart rate baseline) of greater than 15 beats per minute above the resting baseline was sustained for one minute or longer.

8.3.5 Statistical analysis

Standard statistical tests for differences of independent percentages were applied, yielding approximate X^2_1 statistics, or equivalently z-statistics. Other tests examined differences of dependent percentages for which McNemar's X^2 is usual. Percentages are presented with their standard errors.

8.4 RESULTS

A positive FHR response to the MS was observed in 35 (87.5%, SE=5.2%) of the 40 fetuses examined (fig 8.4). Significantly fewer of the fetuses displayed a positive FHR change during the control period (McNemar's $X^2 = 32.0$, $p < 0.000001$). The VS elicited a positive FHR response in all 40 fetuses. The difference of percentages between the MS and the VS is significant (McNemar's $X^2 = 5.00$; $p < 0.05$). The evoked positive FHR responses included both acceleration and a sustained tachycardia (fig 8.5).

Response to vibroacoustic stimulation occurred regardless of the FHR variability. Positive FHR response to the MS was significantly more frequent amongst fetuses in periods of high as opposed to low FHR variability (Diff = 31.3%; SE = 11.6%; $p < 0.001$). The MS did not elicit a response in 5 of the 16 fetuses which had music presented during a period of low FHR variability. After vibroacoustic stimulation, all five of these fetuses exhibited a high FHR variability pattern. Thereafter, additional music stimulation (beyond the designed experimental period) resulted in a positive FHR response. It is inferred that the initial non-response was due to the state of low FHR variability prior to vibroacoustic stimulation.

Response variance with regard to order of testing periods was also examined. When presentation of the music stimulation preceded the vibroacoustic stimulation, the percentage of positive responses to the MS was 70.59% (SE = 11.0%). However, when the music period followed the vibroacoustic period, there was 100% positive response to the MS. The difference is significant ($p < 0.0001$). Given that a FHR response occurred following a

FETAL HEART RATE RESPONSE TO A MUSIC STIMULUS

particular stimulus it generally occurred within the first five seconds after the end of the stimulus (the percentages for music and vibroacoustic stimuli being respectively 93.1%, SE = 2.5% and 98.0%, SE = 1.2%, $p < 0.01$). The 60-second MS elicited more frequent responses than the 15-second MS (the difference in response percentages being 27.5%, SE = 3.5%; $p < 0.000001$).

Maternally-perceived fetal movement was associated with a greater percentage of individual FHR responses to the vibroacoustic stimuli (46.3%, SE = 4.1%) than to the music stimuli (29.7%, SE = 4.5%) ($p < 0.0001$).

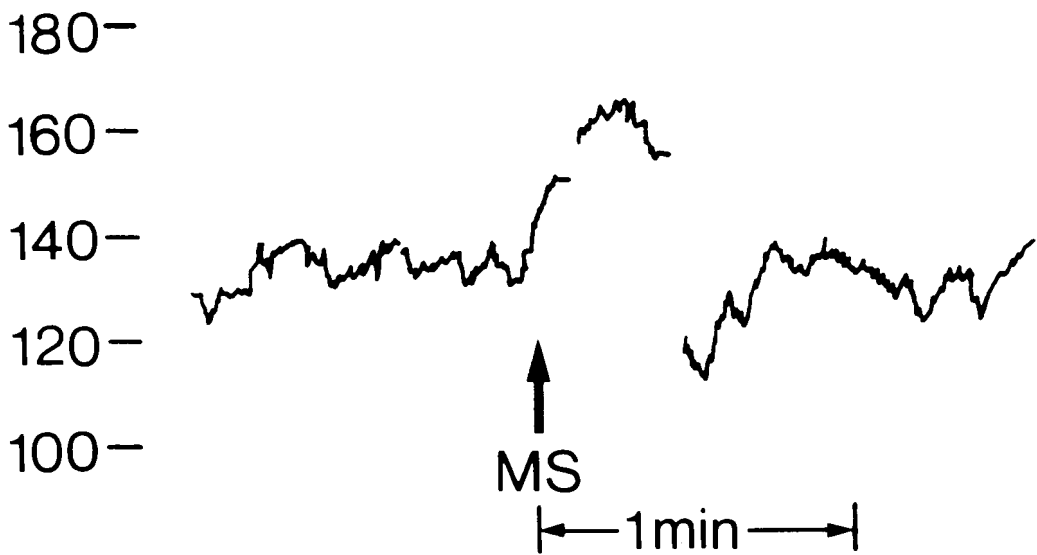


FIG 8.4. *An example of a FHR acceleration in response to the presentation of a music stimulus.*

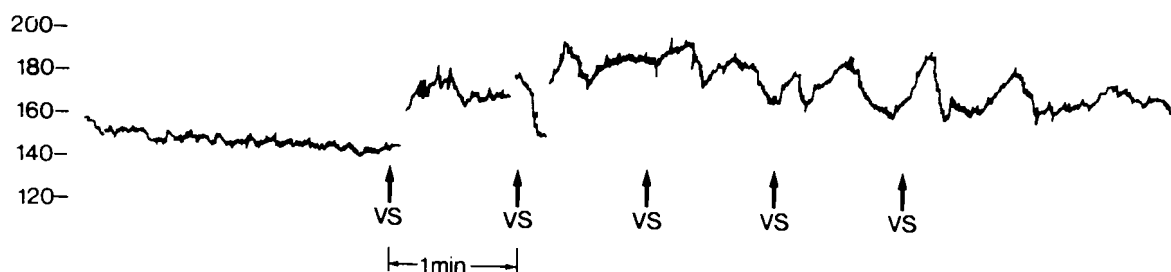


FIG 8.5. *An example of FHR acceleration and tachycardia in response to the presentation of vibroacoustic stimuli.*

8.5 DISCUSSION

This study demonstrates that a normal fetus of at least 32 weeks gestational age shows a FHR response to a music stimulus. The state of neurological arousal and the nature of the sound source (music vs noise) are shown to influence the response.

The positive FHR response to AS, as determined in this study, is consistent with existing literature (Grimwade et al. 1971, Jensen 1984). Measurement of fetal response specifically to music has not been widely published. Olds (1985) reported the influence of periods of music stimulation on mean FHR variabilities when comparing results with a control period.

The characteristics of the two sound sources used in the present study differ. The fetal acoustic stimulator delivered a vibroacoustic signal of predominantly low frequencies with a vibratory component which the mothers reported feeling. The MS had a wider frequency range. Although the music obviously changes constantly in sound pressure level and pitch, the particular extract from this organ work was chosen because of its relatively consistent sound with regard to timbre, pitch, pulse, rhythms and sound pressure levels. The mothers reported no tangible vibration during presentation of the MS. Analysis of the MS revealed that sound pressure levels above 90 dB occurred only at frequencies between 450 Hz and 2250 Hz. Attenuation of external sounds has been shown to occur as a function of frequency, for example by 2 dB at 250 Hz, 14 dB at 500 Hz and 20.4 dB at 1000 Hz (Querleu et al. 1981). The fetal acoustic stimulator presented a low frequency buzzing noise at a non-adjustable sound pressure level of 74 dB measured at 1 m in the air. However, as the fetal acoustic stimulator is held directly against the abdomen, this measurement has little relevancy to the intrauterine level, which has been measured at 90 dB (Arulkumaran et al. 1992). While it was considered sufficient to present the noise for a period of 2 seconds, it was decided that music (which exists in the passage of time) may require longer presentation.

It has been suggested that the vibroacoustic sound source used in the AST, elicits a startle response (Divon et al. 1985). This theory is supported by the finding in the present study that the VS consistently elicited positive responses, even during periods of low FHR variability (this being consistent with research by Leader et al. 1984). The response to music stimulation differed because it was more dependent on the state of neurological arousal, with all the non-responses occurring during periods of low FHR variability. While some of the "responses" may have been random fluctuations in the heart rate, attention

is drawn to the control period which determined significantly fewer positive FHR changes ($p < 0.000001$).

The study confirms reports by Smith et al. (1986), that the acoustic stimulation test reduces the testing time required for the non stress test. The sound generated by the fetal acoustic stimulator elicited a response even on a non-reactive tracing. Without it a prolonged testing time would have been required.

There was a slight trend towards habituation of FHR response to the five stimuli presented. Based on research by Leader et al. (1982a), it is suggested that further presentations of stimuli may result in complete habituation of response. The trend towards more frequent FHR responses to the 60-second MS than to the 15-second MS indicates that habituation to a continuous music stimulus would require a longer period than one minute.

The results of this study indicate that the normal fetus of at least 32 weeks gestational age, is able to perceive music and respond to it. It is demonstrated that differences exist between response to music and response to noise. Society's responsibility for determining and ensuring optimal sound environments for the fetus is prompted by evidence that chronic noise exposure reduces human prenatal growth and that auditory stimulation of the preterm causes calming and therefore increased growth (Schell 1981, Katz 1971, Kramer and Pierpont 1976). Although the cognitive perception involved is speculative, the evidence provided in this study of fetal response to a music stimulus is indicative of some degree of perception of the sound, a fundamental requirement for the concept that the fetus may be influenced by music.

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"Not now Mom, they're playing my song...!"

**NEONATAL BEHAVIOURAL RESPONSE
TO A MUSIC STIMULUS
WHICH HAS BEEN REPEATEDLY PRESENTED
DURING THE INTRAUTERINE STAGE**

9.1 ABSTRACT

Mothers attending childbirth education classes volunteered to listen to a prescribed music excerpt twice daily from the 34th week of pregnancy. Ten neonates (all clinically normal) were tested between the 2nd and 5th day after birth. Investigators observed the effect of two music stimuli, the prescribed stimulus and a non-prescribed stimulus, on neonatal sucking of a non-nutritive nipple. A five-minute control period (C) with no stimulation was compared with a ten-minute period (M) during which two music stimuli were presented. By random allocation, either the prescribed music stimulus (PM) or the novel music stimulus (NM) was presented contingent upon sucking pressure. If a sucking burst was initiated, the PM was activated. On cessation of sucking, the NM was activated. Randomly, the procedure would be reversed for some of the subjects, where initiation of sucking activated the NM and cessation of sucking activated the PM. It was determined that the inter-burst intervals during the M period were significantly extended when coinciding with the PM and significantly shortened when coinciding with the NM. It was concluded that the neonate alters the normal sucking pattern to activate longer periods of

a music stimulus which has been repeatedly presented during the intrauterine stage and shorter periods of a novel music stimulus.

9.2 INTRODUCTION

A plethora of research has indicated response of the third-trimester fetus and the neonate to acoustic stimuli, including measurements of the central nervous system, the autonomic nervous system, behavioural response, electroencephalographic response and psychological/psychophysiological response (Taylor and Mencher 1972, Bennett and Weatherby 1982, Crowell et al. 1985, Trudinger & Boylan 1980, Lecanuet et al. 1989, Gelman et al. 1982, Gerber and Dobkin 1984, Weir 1985, Plessinger and Woods 1986, Rotteveel et al. 1986, Crowell et al. 1980, Salk 1962, Katz 1971, Scheil 1981). The effects of acoustic stimulation on cessation and initiation of non-nutritive sucking in neonates has been demonstrated by Semb and Lipsitt (1968). Modification of neonatal sucking behaviour in response to acoustic stimulation has been determined in several studies (DeCasper & Sigafos 1983, DeCasper & Fifer 1980).

The neonate possesses the capability of discriminating the phonetic components of speech, is sensitive to pitch variation and stimulus rate, is able to discriminate between different voices and is able to localise sounds (Aslin et al. 1983, Bertocini et al. 1987a, Weir and Lamb 1990, DeCasper and Fifer 1980, Suzuki et al. 1964, Hammond 1970, Muir and Field 1979, Clifton et al. 1981). Neonatal movement has been shown to be synchronous with adult speech (Condon and Sander 1974).

Investigations of acoustic short-term memory and learning in the third-trimester fetus and neonate have shown evidence of habituation (the gradual cessation of response to a repeated acoustic stimulus), conditioning (recruiting a new response to a previously neutral stimulus) and operant learning (modifying behaviour by means of negative or positive acoustic reinforcement) (Lecanuet et al. 1986, Shalev et al. 1989, Brody et al. 1984, Bartoshuk 1962, Spelt 1948, Lipsitt & Kaye 1964, Marquis 1931, Aldrich 1928, DeCasper & Sigafos 1983, DeCasper & Fifer 1980). Other tests have indicated auditory long-term

memory from the prenatal stage, for example memory of the maternal voice, maternal heartbeat, uterine sounds, the parental vocal language, and sounds which had been repeatedly presented towards the end of the pregnancy, such as a noise, a passage of spoken prose and the theme tune of a popular TV 'soap opera' (Querleu et al. 1984; Salk 1962; Murooka et al. 1976; Rosner & Doherty 1979; Mehler et al. 1988; Damstra-Wijmenga 1988; Spence & DeCasper 1982; Hepper 1988). The author speculates that the change of neonatal behaviour in the present study, associated with the lengthening of the music presented repeatedly before birth and the shortening of the novel stimulus, may indicate a conditioning to and preference for music heard repeatedly during the intrauterine stage.

The perception of sound as 'noise' or 'music', pleasant or noxious, soothing or alerting, etc., may be a product of learning and conditioning. How the fetus cognitively or psychologically perceives music is a matter of speculation. Considering the discriminatory auditory ability of the neonate, one wonders to what extent the fetus is able to process acoustic information and to possess auditory memory and learning capacities. Music exists in the passage of time. If the fetus were able to perceive music as more than a series of momentary musical sounds, unrelated to any other, then some degree of auditory discrimination and memory would be required.

The aim of the present study was to determine neonatal behavioural changes in sucking activity when exposed to music which has been repeatedly presented during the intrauterine stage. By conducting an operant learning test, consistent behavioural changes associated with presentation of the prescribed music stimulus and a non-prescribed music stimulus may indicate the reinforcing value of the two stimuli.

9.3 METHODS AND MATERIALS

9.3.1 Subject selection

Mothers attending several private antenatal childbirth education classes and registered for admission to the Vincent Pallotti Hospital, the Libertas Hospital, City Park and the Panorama Hospital were informed of the procedures involved in the research project and a request made for volunteers. These volunteers were accepted if they were able to provide a tape recorder for their own use, from the 34th week of pregnancy until the birth of the baby. Sixty volunteers were recruited for the study, with the expectation of a high drop-out rate. Inclusion criteria for neonates consisted of a maternal history free of complications during the pregnancy, a family history free of congenital deafness, gestational age of 38 to 42 weeks, birthweight of at least 2000g, Apgar score of at least 8 at 5 minutes after birth, classification as healthy at time of testing. Neonates were to be in a postprandial quiet awake state. Ten neonates were tested, being the only subjects having met all the inclusion criteria.

9.3.2 Materials

Recordings were made of the stimulus material, using a CD player, amplifier, tape recorder and audio cassettes. Two music excerpts, one of Western Classical style and one of Jazz style, were used as stimuli: 'Nimrod' from the Enigma variations by Elgar and 'Mirrors' by Charles Lloyd. Each mother was required to provide a tape recorder for her own use. During neonatal testing, the music was presented by means of a Hitachi portable tape recorder model TRK3D, delivering a sound pressure level (SPL) of approximately 70 dB. Average sound pressure levels (SPLs) were measured by means of a Brüel and Kjaer sound level meter type 2203. A non-nutritive nipple was attached to a custom-made pressure transducer by means of a plastic tube, with a clamp attached for adjusting air pressure (fig 9.1). This was linked to a

Brüel and Kjaer Level Recorder, Type 2306, which traced the pressure levels, thus recording neonatal sucking activity (fig 9.1).



FIG 9.1. The Brüel and Kjaer level recorder, type 2306 (left) and the custom-made pressure transducer (right).

9.3.3 Procedure

The investigator attended childbirth education classes in order to inform mothers of the test. The audio cassettes (each with one of the two music stimuli) were selected for preference by those mothers who volunteered to take part in the study. Instruction was given to the women to listen to the prescribed piece of music at least twice a day from 34 weeks of pregnancy. Further instructions included volume

level, which was to be at least that of normal conversation, but not loud enough to be unpleasant. The women were also instructed not to listen to the music after the birth had taken place, until the neonatal test had been completed.

The participants were asked to contact the investigator soon after the birth had taken place. Maternal consent was obtained prior to onset of testing. Subjects were tested between 2 and 5 days after the birth at a time convenient to the hospital staff and the mother. Testing took place post-prandially (whether the neonates were on fixed feeding schemes or not).

The mother and baby were escorted to a testing room where the room temperature was kept warm, lighting was low so as not to be distracting from the sound stimuli, and background noise level was kept to a minimum. The baby was dressed in a vest and disposable nappy. The mother was seated with the baby on her lap. The baby was held facing the mother in a supine position, with the head supported by the mother's one hand. The testing equipment was placed a half metre away from the neonate. The neonate was required to be in a quiet alert state prior to onset of testing. When necessary, speaking, stroking and holding were used before testing began in order to achieve this state. The nipple and plastic tubing which linked it to the sound pressure transducer were washed in salt water and sterilised in Milton for 30 minutes. The nipple was lightly held in the baby's mouth by the mother (fig 9.2). During testing, the mother was instructed to look at the baby, but not to change her facial expression or speak and not to move the nipple.

A two-minute period was allowed for the baby to adjust to the situation of sucking the non-nutritive nipple (fig 9.3). This was followed by a five-minute control period (C) with no acoustic stimulation and then a ten minute period of music stimulation, divided for analysis periods into two five-minute periods (M1 and M2).



FIG 9.2. *The setting for the presentation of music stimulation to the neonate.*

During the music period, either the prescribed music stimulus (PM) or the novel music stimulus (NM) was presented contingent upon sucking pressure. If a sucking burst was initiated, the PM was activated. On cessation of sucking, the NM was activated. Randomly the procedure would be reversed for some of the subjects, where initiation of sucking activated the NM and cessation of sucking activated the PM. If the state of baby changed, testing was temporarily halted. If the required state was not regained within 10 minutes, testing was postponed to another occasion.



FIG 9.3. The neonate sucking the non-nutritive nipple linked by means of a plastic tube to the pressure transducer.

9.3.4 Data analysis

The tracings were analysed by two investigators (SW and NC) and agreement was required for the determination of the number of sucking bursts and the length of inter-burst intervals. A burst of sucking was defined as a series of sucks separated from another by at least one

second. Sucking activity during the control (C) period was compared with the first five minutes of the music period (M1) and with the second five minutes of the music period (M2).

9.3.5 Statistical analysis

Statistical evidence was sought to indicate differences between the I group (the group in which the prescribed music stimulus was presented during the inter-burst intervals) and the S group (the group in which the prescribed music stimulus was presented during the sucking bursts), using the means, standard errors of the means (SE) and paired t-tests. Since the use of the t-test on such small samples may be criticized because of possible non-normal distributions of the differences, corroboration of findings was sought using the Mann-Whitney test (Conover 1971). The Mann-Whitney test makes minimal assumptions, ignores the relative sizes of the data values and focuses only on the ranked data values. It is always valid for the comparison of relative sizes of values in two data tests.

9.4 RESULTS

The I group (in which the PM was presented during the inter-burst intervals) and the S group (in which the PM was presented during the sucking bursts), were comparable during the C period. The differences in the total inter-sucking time between the groups were statistically non-significant (172 ± 18 vs 193 ± 37 seconds), as were the differences in the numbers of sucking bursts between the groups (24 ± 2.9 vs 18 ± 4.3 bursts). This finding allows us to reasonably infer that changes within and differences between the groups were the result of the presentation of the music stimuli.

It was observed that the changes in the neonatal sucking activity resulted in lengthening of the presentations of the prescribed music and shortening of the presentations of the nonprescribed music. It was determined that the inter-burst intervals during the second half of the music period (M2) were

significantly extended when coinciding with the PS and significantly shortened when coinciding with the NS (fig 9.4).

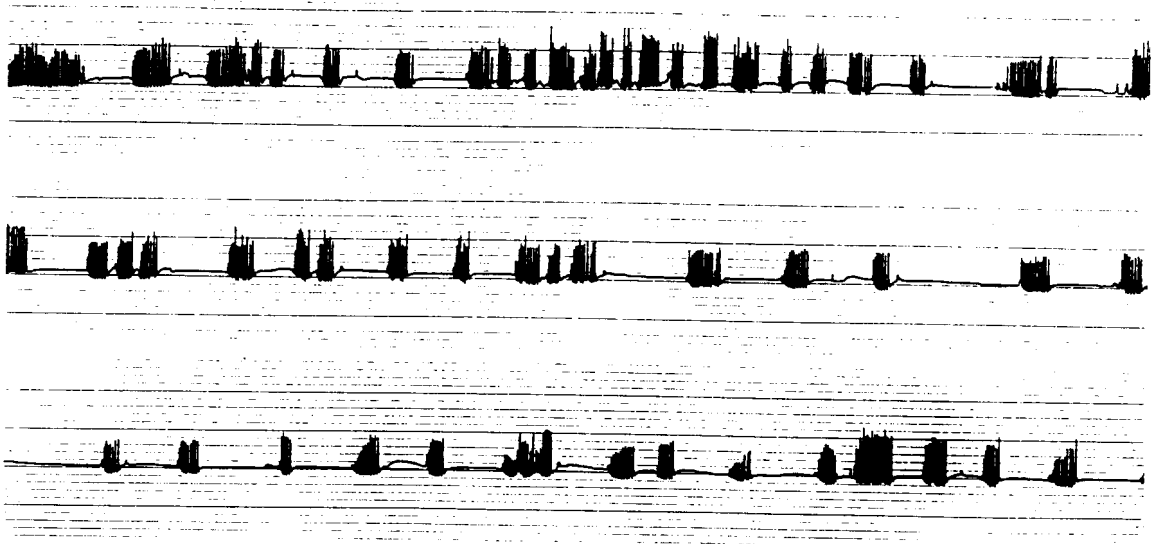


FIG 9.4. A tracing of neonatal sucking activity divided into three five-minute periods in which the inter-sucking time determined in the control period (top section) is shown to increase during the first and second five-minute periods of music stimulation (middle and lower sections).

Because the changes in sucking activity are considered to be the result of an operant learning process during the music stimulation period, in which a gradation of change would be expected, comparison is made between the control period (C) and the second five minutes of the music period (M2). Group I exhibited a significant increase in the inter-sucking time during the M2

period compared with the C period (mean change \pm SE = 79 ± 10 seconds; one-sample t-test = 7.79). The evidence against a null hypothesis of zero changes is confirmed by the Mann-Whitney test ($p < 0.0001$). The tabulated results indicate the gradation of change which occurred between the C period, the M1 period and the M2 period (table 9.1). Group S exhibited a significant decrease in the inter-sucking time during the M2 period, compared with the C period: mean \pm SE = 74 ± 32 seconds; one-sample t-test = -2.30 (table 9.1).

On the basis of the (two-tail) two sample t-statistic ($t = 4.56$) it may be claimed that the I and S groups are significantly different from one another in their average changes of the total inter-sucking time between the C period and the M2 period. The (two-tail) Mann-Whitney test confirms this result ($p < 0.001$) (table 9.2).

The I group exhibited a significant decrease in the number of sucking bursts between the C period and the M2 period (mean \pm SE = 13.0 ± 4.5 bursts; one-sample t-statistic = 2.83) (table 9.3). A non-parametric test against a null hypothesis of randomly fluctuating numbers of sucking bursts leads to its rejection ($p < 0.02$). In the S group a minor increase occurred in the number of sucking bursts between the C period and the M2 period (mean \pm SE = 9.0 ± 6.7 bursts; one-sample t-statistic = -1.30). The two sample t-tests ($t = 2.66$) suggest a significant difference between the I group and the S group in the changes to the number of sucking bursts occurring in the M2 period compared with the C period ($p < 0.025$). This result is confirmed by the Mann-Whitney test ($p < 0.01$) (table 9.4).

TABLE 9.1 CHANGES IN INTER-SUCKING TIME BETWEEN C AND M2 PERIODS

I GROUP			
PERIODS	MEAN SE	ONE-SAMPLE T-STATISTIC	MANN-WHITNEY P-VALUES
C - M1	43 ± 12	3.48	P < 0.01
M1 - M2	37 ± 8	4.41	P < 0.005
C - M2	79 ± 10	7.97	P < 0.0001

S GROUP		
PERIODS	MEAN SE	ONE-SAMPLE T-STATISTIC
C - M1	-44 ± 38	-1.15
M1 - M2	-29 ± 20	-1.47
C - M2	-74 ± 32	-2.30

TABLE 9.2. DIFFERENCE IN CHANGES BETWEEN THE I GROUP AND S GROUP

PERIODS	TWO-SAMPLE T-STATISTIC	MANN-WHITNEY P-VALUES
C - M1	2.15	p < 0.05
M1 - M2	3.04	p < 0.01
C - M2	4.56	p < 0.001

TABLE 9.3 CHANGES IN NUMBER OF BURSTS BETWEEN C AND M2 PERIODS

I GROUP		
PERIODS	MEAN SE	ONE-SAMPLE T-STATISTIC
C - M1	7.5 ± 3.8	1.96
M1 - M2	5.3 ± 1.6	3.32
C - M2	13.0 ± 4.5	2.83

S GROUP		
PERIODS	MEAN SE	ONE-SAMPLE T-STATISTIC
C - M1	-6.0 ± 5.7	-1.05
M1 - M2	-3.0 ± 1.9	-1.42
C - M2	-9.0 ± 6.7	-1.30

TABLE 9.4 DIFFERENCE IN CHANGES BETWEEN THE I GROUP AND S GROUP

PERIODS	TWO-SAMPLE T-STATISTIC P-VALUES	MANN-WHITNEY
C - M1	1.97	p < 0.01
M1 - M2	3.21	p < 0.01
C - M2	2.66	p < 0.01

9.5 DISCUSSION

Although non-nutritive sucking does not provide the physical benefits of nutritive sucking, it is usually an activity wherein the neonate will readily engage. It is considered beneficial that the restrictions and variables intrinsic in nutritive sucking are avoided, such as the need to use only bottle-fed babies, to consider variables in the size of the hole in the nipple or the amount of time each baby spends in feeding, etc. Furthermore the study does not interfere with the normal feeding pattern of the neonate. It was not assumed that the babies would be on fixed feeding schemes and the tests were conducted at times agreed upon by the mother and nursing staff. The hospitals concerned usually provided a private telephone for each mother, thus allowing her to inform the investigator of convenient testing times at short notice.

The two music stimuli used in the study were selected in view of their consistently tranquil quality including slow pulse, unhurried rhythms, a lack of harsh timbres and no sudden changes in intensity levels. However the styles of the pieces were different, the one being a Western Classical work from the 19th century and the other a contemporary Jazz piece. It was considered important that the mothers select one of the two tapes on the basis of preference, as there would be less likelihood of co-operation if the mother did not find pleasure in listening to the piece.

Of the 50 mothers who volunteered to take part in the study, 26 attempted the procedure but failed to persevere with listening to the music tape for the required minimum number of times per day. Five mothers failed to timeously notify the investigator of the birth in order that the test be conducted within the prescribed number of days. In the group of neonates whose mothers had fulfilled the requirements, there was one postnatal death, three premature births, one neonate diagnosed as severely jaundiced and two neonates who failed to achieve the required state of arousal. On one occasion the equipment malfunctioned. One completed test was discarded as it was later discovered that the neonate had not been in a postprandial state.

The operant learning task required that the neonate (by random allocation) either shorten or lengthen the inter-burst sucking interval, in order to activate longer or shorter presentations of the two music stimuli. By selecting and continuing with the required method, the reinforcing capability of the associated music was indicated. The results of the study indicate that the changes in the length of the inter-burst intervals which occurred in neonatal sucking behaviour during the music stimulation period were associated with lengthening of the presentations of the prescribed music and shortening of the presentations of the nonprescribed music. These results are consistent with the findings of DeCasper and Fifer (1980), involving neonatal activation of either a recording of the maternal voice or an unfamiliar voice, and the findings of DeCasper and Sigafos (1983), involving the presentation of heartbeat sounds.

The significance of the results may be speculative: does the neonate recognize the music which had been presented during the intrauterine stage; is the perception of the sound associated with pleasure or displeasure; is there indication of conditioning to and preference for familiar music? The wealth of studies of fetal and neonatal auditory competency indicate the probable perception of music, or aspects of it. While it may be presumptuous to infer from the results of this study that the experience associated with the prescribed music was pleasurable, the lack of crying or distressed facial grimacing do indicate that the experience of both music stimuli was not traumatic.

It is speculated that the modification of behaviour which occurred, associated with activation of extended periods of familiar music, provides possible indication of conditioning to and preference for familiar music. The significance of any learning in the fetal and neonatal stages on long-term musical conditioning and skill must still be determined. In the quest to provide the fetus and neonate with an optimal acoustic environment, additional investigation may provide the necessary clarification regarding the hearing and the auditory perceptual and cognitive abilities of the fetus and neonate, indicating the extent of musical influence which occurs before birth.

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CONCLUSION

The inherent value of music in enriching human life - aesthetically, cognitively, emotionally, spiritually - is so vast as to be inestimable, and has been referred to by authors and philosophers throughout the ages:

"Education in music is most sovereign because more than anything else, rhythm and harmony find their way into the secret places of the soul" (Plato. The Republic. Bk iii sec 401).

The extent of fetal and neonatal experience of music is currently impossible to estimate. However, the maturity of peripheral auditory mechanisms, the activity of the auditory nerve and the electrical activity of the cortex and brainstem together indicate probable hearing function by the 25th week (described in chapter 2). Studies of response to acoustic stimulation indicate not only perception of sounds, but memory of sounds from the intrauterine stage, neonatal discrimination of differences between sounds (such as frequency, timbre, intensity, duration, rhythm and the various phonetic components of speech) and interpretation of the significance of sound (described in chapter 6). However, questions remain regarding early cognitive perception of music and the psychological influences of music on the developing human. Further research may provide the necessary clarification regarding the extent of these functions and the long term effects of early exposure to music.

The consequential value of early experience is widely assumed:

"Early handling could be more important than later handling in the sense that it would influence a greater number of subsequent events than would late handling" (Fiske and Maddi 1961 p100).

Music stimulation in the pre- and postnatal periods is, in the light of research reviewed in this document, suggested to influence the fetus and neonate in the following areas:

NEUROLOGICAL AND PHYSIOLOGICAL DEVELOPMENT

"A brain scientist who cannot himself compose or perform music may well despair of his ability to 'enter the mind of', that is to say define the specific cerebral aptitudes of even the humblest musician, let alone those immortals whose achievements mark some of the summits so far scaled by living brains. He can take comfort, however, in the certainty that a musician-neurologist who himself had cultivated these high aptitudes would be no nearer to an understanding of the brain structures and brain processes on which these aptitudes depend" (Phillips 1977 p48).

It is clearly evident in the literature that the third-trimester fetus and the neonate experience sound and have the capacity to remember, interpret and discriminate between certain sounds. However, knowledge of the cognitive processes involved in fetal and neonatal experience of music is largely speculative.

What is the "neurologic, physiologic and psychologic effect of a musically enriched or deprived environment" during the prenatal and postnatal stages? (Roehmann 1991). There appears to be a critical developmental period in which widely varied sound must be received for the central auditory system to mature normally (Webster and Webster 1977). When deprived of sound stimulation, the central auditory system does not develop normally in the brain stem. This is evidenced by the profound central neural changes in the brain stem auditory nuclei associated with sound deprivation (Webster and Webster 1977). For normal maturity of auditory function to occur, therefore, one must presume that varied auditory stimulation is of critical importance. A deprived period may result in an omission in the normal infant's pattern of sequential development, which may be of permanent effect (Rothchild 1966). A study of auditory responsivity in incubated preterm infants determined greater

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responsivity in those infants who had received 4 to 8 weeks of auditory stimulation than those who had not (Segall 1972). Stimulation in the perinatal period is believed to influence the development of neural and behavioural patterns (Reisen 1961).

It has been established that the intrauterine acoustic environment consists of a diversity of sounds, from both internal and external sources (chapters 1, 7). It is suggested that by adding music to that environment, a further stimulus for auditory development is provided. It would be reasonable to assume that the more experience of varied sound or music, the greater the potential for the development of listening and auditory discrimination skills. The acquisition of vocal language skills involves a process requiring similar auditory perception, discrimination and imitation processes to those occurring in the development of musical skills. The need for investigation into the possible influence of music experience on the development of vocal language skills is suggested by the author.

PSYCHOLOGICAL DEVELOPMENT

Music is known to have power to influence human emotion, although this influence may be due to inherent components of the music and/or learned associations (Radocy and Boyle 1979, Pratt 1954, Noy 1967). If the fetus and neonate do experience music, then it is possible that there may be some psychological influence involved in such encounters. While fetal and neonatal response to sound has been repeatedly confirmed (measured in terms of central nervous system indices, autonomic nervous system measures, behavioural responses and electroencephalic responses), information regarding the psychological and emotional influence of sound, and specifically music, is less abundant. However, studies referring to the deleterious psychophysiological effects of noise on the fetus provide some indication of the need to determine optimal acoustic environments for the pre- and postnatal infant (Schell 1981, Ando and Hattori 1977). Furthermore, the psychological and emotional influence of sound on the neonate is evidenced by several studies (Murooka et al. 1976, Salk 1962, Hepper 1988). The

ameliorative effect of sound stimulation on the premature infant, by decreasing restlessness and enhancing weight gain, indicates the psychological influence of sound on the infant from before 40 weeks gestational age (Katz 1971, Kramer and Pierpont 1976). Early psychological influence of sound may further be indicated by the studies revealing the reinforcing value on the neonate of sounds from the intrauterine environment (DeCasper and Fifer 1980, DeCasper and Sigafos 1983).

The possibilities for the therapeutic use of music for the pre-, peri, and postnatal infant are indicated by these studies of the psychophysiological influences of sound. The incubated preterm neonate, deprived of the auditory stimulation of the uterine environment, is also isolated from the auditory stimulation to which the normal neonate would be exposed.

Separation from the maternal figure (being a prime contributor of stimulation) and restriction to a world of minimal sensory stimuli is believed to lead to adaptive mechanisms in the form of developmental variations (Katz 1971). The author suggests that the possibilities for the use of music in providing a milieu which will benefit developmental and behavioural outcome, be investigated. But what is the optimal acoustic environment for the incubated infant? Should it mimic that of the womb or the world? Is the effect of calming more desirable than that of alertness or is each appropriate at certain times or ages (Cornell and Gottfried 1976, Field 1980)? The endorsement and adoption of music stimulation programmes for the premature infant should be based on extensive research.

Besides the possible psychophysiological benefits of music, therapeutic value through musical experience may be found in the promotion of parent/child bonding. It seems reasonable that an activity involving a means for parents to communicate or share pleasurable experience with their unborn or newborn child may enhance this bonding process. It has been stated that "the importance of singing or humming to a baby is not in the musicianship but in the communication of a unique relationship" (Lind and Hardgrove 1978 p10).

The psychological influence of music on the mother in the birthing environment has been described (chapter 4). The role of sound in directly

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influencing the emerging baby needs investigation, not only regarding the elimination of harsh sounds from the birthing environment, but regarding presentation of music for the benefit of the baby.

It is commonly heard that the music of one composer may be more appropriate than that of another during the pre- and postnatal stages. Whether optimal means soothing or eliciting arousal, or any other effect or combination of influences, is a question still to be answered.

"All music exists on a continuum between highly stimulating, invigorating music and soothing, sedating music" (Gaston 1968 p18).

Certainly, if the emotional influence of music on the mother effects her unborn child, then consideration should be given to the fact that

"what's one man's poison, signior, is another's meat or drink"
(Beaumont and Fletcher. Love's Cure. Act iii Sc 2).

MUSIC LEARNING

Investigation of the routes to musical competence must necessarily span the influences occurring in the pre- and postnatal stages. Fetal and neonatal capacities in auditory discrimination, memory, habituation and conditioning indicate how early music learning potential may exist. The mechanical process of hearing must be distinguished from listening intelligence. Elliott (1992) describes listening as 'a covert form of thinking-in-action and knowing-in-action' and as 'a context-dependent process'.

"Under certain conditions we expect change, under others continuity, and under still others repetition...expectation is always ahead of the music, creating a background of diffuse tension against which particular delays articulate the affective curve and create meaning" (Meyer 1959 p59).

How music sounds to the 'musically-inexperienced' fetus or neonate is unknown. Further research may reveal how the fetal or neonatal brain connects, discriminates, interprets and relates musical sounds and silences. The profound revelation that the fetus and neonate do become 'experienced' in sounds of the environment (showing evidence of auditory habituation, conditioning and operant learning) admonishes society's neglect in the design of an optimal sound environment for the developing young human life.

Although fetal perception and learning of music still need extensive investigation, the author suggests that music stimulation in the pre- and postnatal period provides the infant with the opportunity for any music learning potential which may exist. Whether this period is "more propitious for the acquisition of musical skills" than any other has not been established (Roehmann 1991). Does the prolific stage of neurological growth which occurs in pre- and postnatal stages constitute a "window of opportunity" for the experience and learning of music? If musical experience does not occur in this period, does the extent of potential remain forever unrealised? A vast field lies unexplored in the need to develop

"the kinds of explanatory theories about the causes and origins of excellence in music that will make it possible to design more effective learning experiences" (Howe and Sloboda 1991 p49).

The auditory stimulation required for the development of the central auditory system (Webster and Webster 1977) leads one to consider whether the pre- and postnatal stages constitute a critical period for the establishment of the neural auditory processing skills which will determine music activity and listening skills in the long-term. Auditory responsivity in incubated preterm infants is determined to be greater in those infants who have received 4 to 8 weeks of auditory stimulation than those who have not (Segall 1972). Total auditory deprivation in early life is stated to result in "irreversible inability to perceive speech sounds" (Northern and Downs 1984). Language exposure in the period before two years of age appears to be critical. Rehabilitation of the deaf, implemented from two years of age, is shown to result in only partial reversibility in language learning deficits (Lenneberg 1967). A study of institutionalised homeless infants in Lebanon, indicated that the intellectual

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functioning in those adopted after the age of two remained retarded, while those adopted before two reached normal intellectual function (Dennis 1973). Northern and Downs (1984) compare the situations of a boy raised in the wild who never attained language function (Lane 1977) with the girl locked in a closet for 11 years (Fromkin et al. 1974). It was suggested that the girl's initial 20 month exposure to family life was responsible for her achievements in language abilities.

"It seems as if even a short exposure to language, a brief moment during which the curtain has been lifted and oral communication established, is sufficient to give a child some foundation on which much later language may be based" (Lenneberg 1967).

Musicality is a biologically predetermined human intelligence, as is language (Gardner 1983). The latent potential of man's inherent musicality is released through musical exposure and experience. Observing the natural way in which young children learn vocal languages, it could be assumed that infants learn to imitate the musical language of the environment in a similar manner. A vocal language which does not exist in the environment does not develop in the child. Although musicality (in the form of basic discriminational senses of pitch, dynamics, timing and timbre) is inherent in the human, listening, composing or performing skills within a particular music genre should not be expected to develop in an auditory vacuum of that music genre. As in the case of speech, the foundation required for music learning is listening, whether conscious or subconscious. Toddlers utter their first words after hearing them repeatedly and evidence of prelinguistic activity is seen in neonatal ability to move in synchrony with adult speech (Condon and Sander 1974). The author suggests that early musical expressions are similarly the product of previous musical exposure. The author suggests that music learning is influenced by the quantity, quality and context of musical exposure which takes place both during and prior to the age at which imitation begins.

"But to withhold from a child the source of pleasure, stimulation, and comfort that music can be - from the very beginning and throughout one's entire life - is, in a sense, comparable with not teaching a child to talk. There is one major difference: the parent who cannot speak himself cannot teach his child to speak. But, that parent who does not have what we might call a 'singing voice' or is not what we call 'musical' can, nevertheless, give his child some form of music" (Lind 1980 p 135).

Music is frequently referred to as a language or a means of nonverbal communication (Gaston 1968). However, far from being a 'universal language,' greater or lesser differences exist between the music of every age and culture. The young child absorbs and imitates the musical vocabulary of his or her culture, which comprises a particular set of formal pitch, melodic, harmonic, rhythmic relationships, characteristic tone colours/timbres/textures, conditioned associations of moods, emotions, meanings, images etc.

"In the music of any given culture, melodic and harmonic sequences are composed out of small sets of pitch relationships, which are said to constitute their scale. The set of notes on the scale thus provides an alphabet in terms of which a melody or harmonic sequence may be defined" (Deutsch 1977 p112).

In many countries formal music education is available to the preschool child, who is well able to mimic simple rhythmic motifs and songs. It may be considered that this is the child's first important stage of musical training. However, by this age the child has already adopted the musical language of his environment and would find it difficult, if not impossible, to sing a song in a 'foreign' mode. Certain attitudes have also been developed towards music, as a result of the context in which it has been presented. In the light of research indicating neonatal recognition memory of, conditioning to and 'preference' for sounds heard prenatally (chapter 6), the author suggests that the pre- and post natal stages may constitute a powerful period of conditioning to the music(s) of one's environment.

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It has been suggested that multicultural music education be introduced to the South African school music curriculum (Gibson 1992, Hauptfleisch 1992, Oehrle 1992, Xulu 1992). Multiculturalism has been defined as:

"a policy of support for exchange among different groups of people to enrich all while respecting and preserving the integrity of each" (Elliott 1989 p14).

The author therefore suggests that where this ideal of multiculturalism exists, exposure to music of the relevant cultures from as early as the fetal stage provides the opportunity for any learning potential which may exist. While some children and adults succeed in 'acquiring' the musical language of a foreign culture, this is obviously dependent on listening to that musical language. It is suggested that the ease with which this learning process occurs, as with the spoken language, may be greatly influenced by the age at which such exposure begins, with greater difficulty experienced when beginning at a later age.

If music does influence the developing human from before birth, then it may be assumed that the context in which music is experienced will affect that experience. Fine music education, seen not in the context of creating a musical genius, but of developing the 'whole' child, cannot but bring children genuine wellbeing, enrichment and happiness.

"Music Education does not mean educating a musician.....it means educating a human being" (Suchomlinsky 1986).

Music education, besides cultivating an appreciation of and love for the aesthetic beauty of music, can nurture skill in music activity, can provide the opportunity for the release of tension and energy, can promote intellectual growth, logical thought, concentration skills, language learning, creativity, emotional expression, the development of fine and gross motor skills, good self-concept, as well as group and social skills.

"Children become more beautiful through 'healthy' music education"
(Solomon 1980).

Solomon (1980) describes music education as a wholistic process: its purpose being not to promote competitiveness and egocentricity, but rather to convey the sheer joy of music. The child, unconsciously absorbing the beauty of music and striving to reproduce that beauty, reflects beauty in his or her inner self, made evident in sensitivity, expression and attitude.

Bestow the beauty of music on the beauty of the young child and from the powerful combination bursts forth a striking wonder.

The investigation into fetal and neonatal experience of music is scarcely begun. The evidence of music penetrating the uterus and of auditory perception, memory and learning before birth still restrict us to much speculation. Borrowing the words of Ballantyne (1892) used to portray the state of fetal care a century ago, the current study of the influence of music in the pre-, peri- and postnatal periods may be described as:

"a field sparsely settled, very vast and intensely alluring".

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ACOUSTIC MEASUREMENTS AND SCALES OF HUMAN HEARING ABILITIES

APPENDIX 1.1 ACOUSTIC MEASUREMENTS

Acoustic measurements referred to in this document involve three scales. In order to express the frequency unit of a sound wave (corresponding to pitch), the Hertz (Hz) is used, measuring cycles per second. The decibel (dB), which is a linear scale, is used to express sound pressure level. Although widely used, problems arise when relating a linear measurements to human hearing ability, which does not correspond to this linear scale. As a result, measurements are sometimes converted to the A-weighted scale (dBA), which corresponds more closely with human hearing abilities by progressively reducing the levels of the lower frequencies to which the human ear is less sensitive (fig A1.1).

APPENDIX 1.2 SCALES OF HUMAN HEARING ABILITIES

The average threshold of human hearing is represented by the lower curve and the maximum sensitivity of feeling/pain by the highest curve in fig A1.2. The human ear perceives dissimilar levels of loudness of different frequencies as being of equal loudness, as illustrated by the equal loudness curves in fig A1.2.

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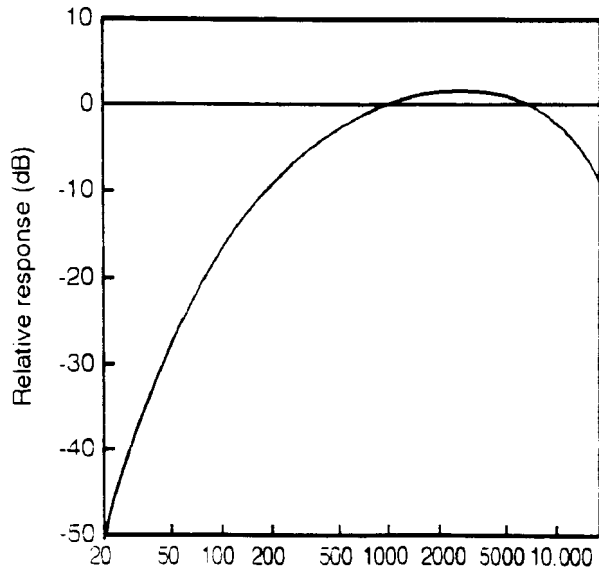


FIG A1.1. *The filter characteristics for A-weighted sound levels (redrawn from Kinsler et al. 1982)*

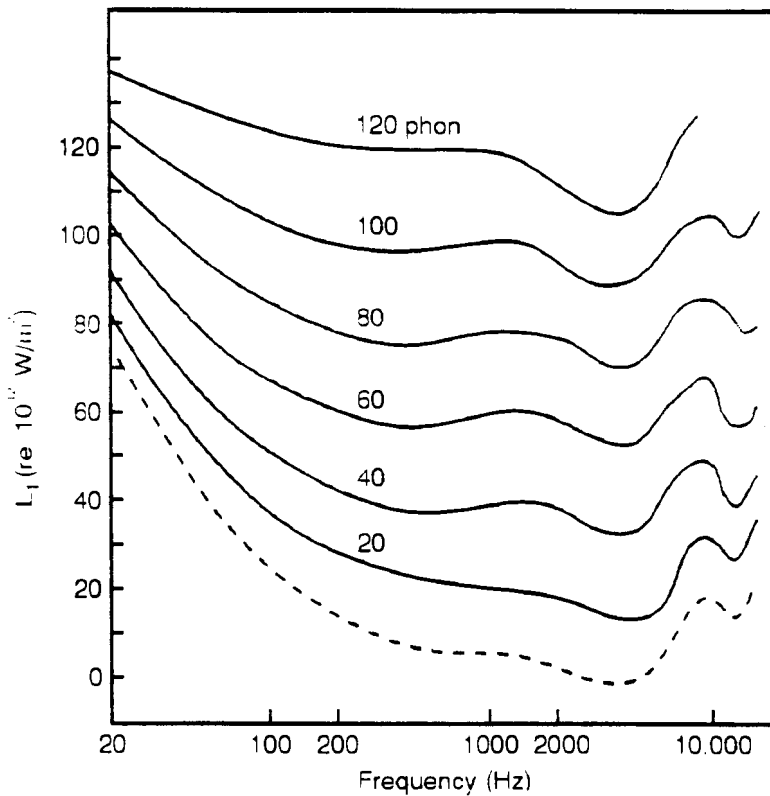


FIG A1.2 *Upper and lower thresholds of human hearing (represented by the highest and lowest curves) and equal loudness curves for pure tones (redrawn from Kinsler et al. 1982)*

APPENDIX 2

**DATA REGARDING EQUIPMENT
USED IN INTRAUTERINE ACOUSTIC RECORDINGS**

Calibration Chart for
Hydrophone Type 8103

Serial No. 75 3771

Brüel & Kjær



Narum Denmark

Reference Sensitivity at 250 Hz* at 23 °C
including 6 m integral cable

Cable Capacitance 95 pF/m typical

Open Circuit Sensitivity:

Voltage Sensitivity:

- 211.5 dB re 1 V/μPa**

- 91.5 dB re 1 V per Pa or 26.6 μV per Pa

- 111.5 dB re 1 V per μbar**

Charge Sensitivity: 95 · 10⁻³ pC per Pa

Capacitance (including 6 m cable) 3570 pF

Frequency Response:

Individual Free Field Frequency Response Curve
attached.

Date 1/11/78 Signature J.D

Summarized Specifications

Usable Frequency Range: 0.1 Hz to 200 kHz (-10 dB)

Linear Frequency Range:

0.1 Hz to 20 kHz ± 1 dB
0.1 Hz to 140 kHz ± 2 dB

Horizontal Directivity 200 kHz: (XY-plane)
typical ± 2 dB

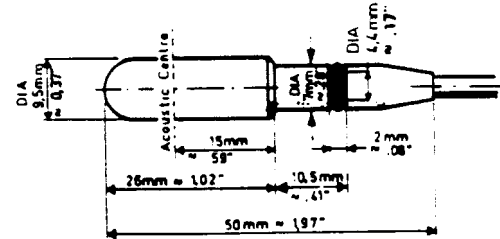


Vertical Directivity 100 kHz: (XZ-plane)
typical ± 4 dB



BC 0094

Physical:



Leakage Resistance:

> 2 · 10⁴ MΩ at 23 °C

Operating Temperature Range:

-40°C to +120°C
-40°F to +248°F

Change of Sensitivity with Temperature:

Charge < 0.03 dB/°C
Voltage < -0.03 dB/°C

Change of Sensitivity with Static Pressure:

3 × 10⁻⁷ dB/Pa (0.03 dB/ato)

Temperature Transient Sensitivity: < 50 Pa/°C

(ANSI S.2.11-1969); measured with B & K Charge
Preamplifier Type 2626, LLF 3 Hz

Allowable Total Radiation Dose: 5 × 10⁷ Rad

Acceleration Sensitivity: < 130 dB re 1 μPa/g

Maximum Operating Static Pressure:

40 ato

Cable:

Double shielded low noise, low capacitance
Integral cable: 6 m with miniature plug

Weight (incl. cable): 170 g

* Traceable to NBS

** 1 Pascal = 1 N/m² = 10 μbar

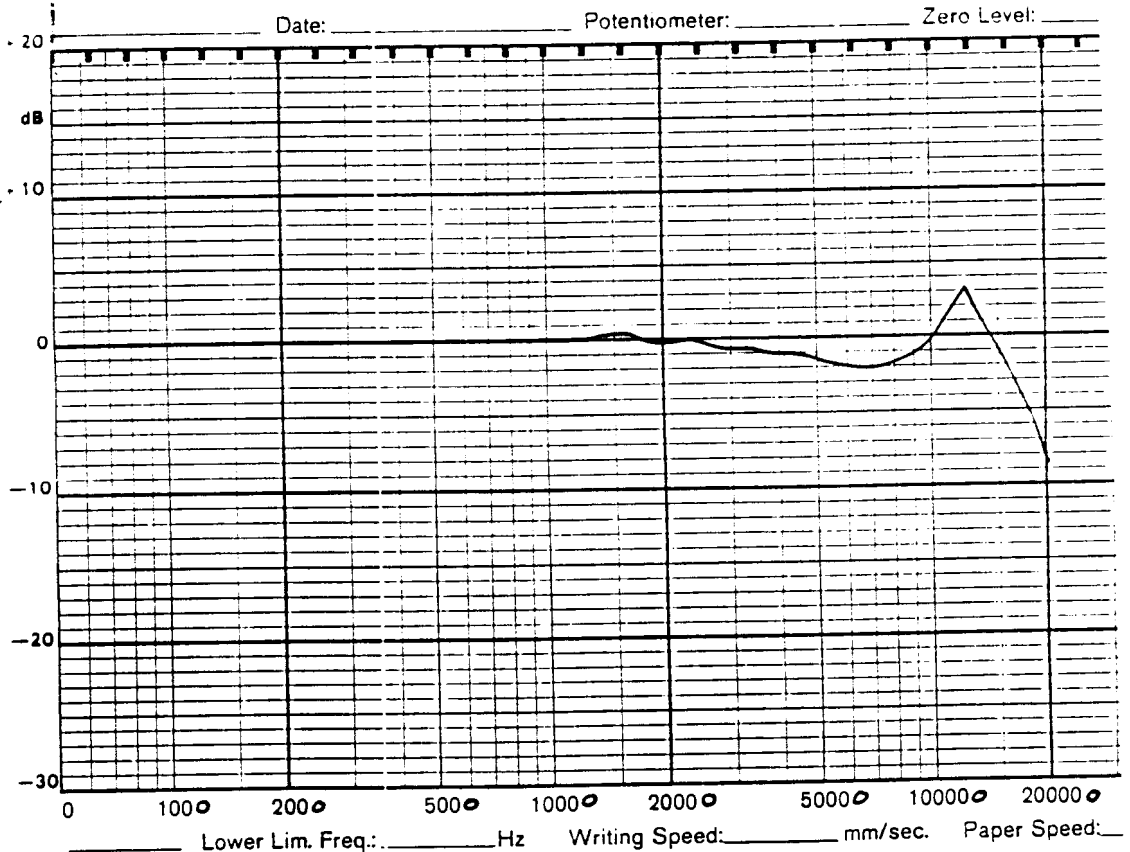
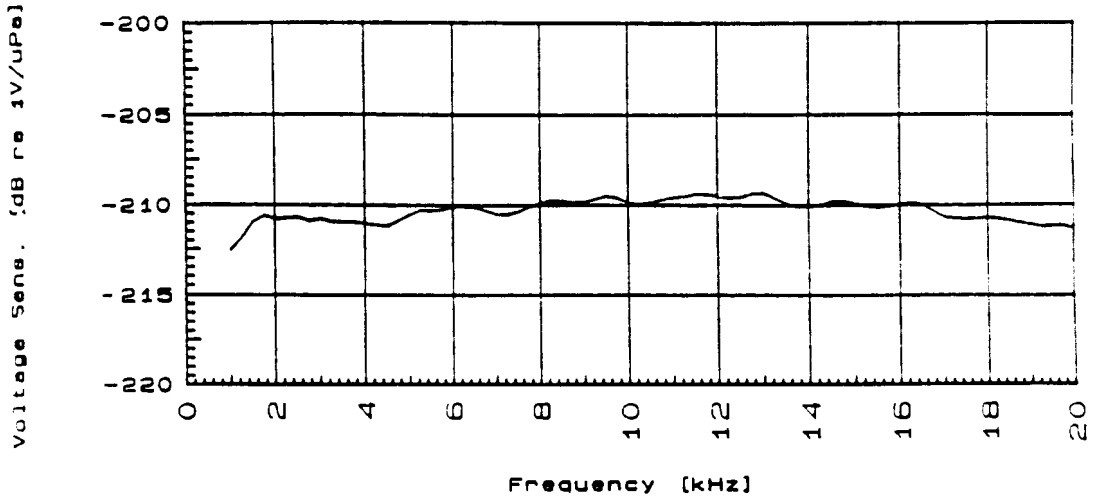


FIG A2.1.

Original calibration certificate for the hydrophone.

Free Field Voltage Response



OPERATOR : BRW	DATE : 7 Nov 1981
FILENAME : STD STD	XDUCER : B+K 8103
REMARKS : # 752771	CAL A082.....
..... N.P. Coley 7/4/91	

FIG A2.2. Updated calibration certificate for the hydrophone

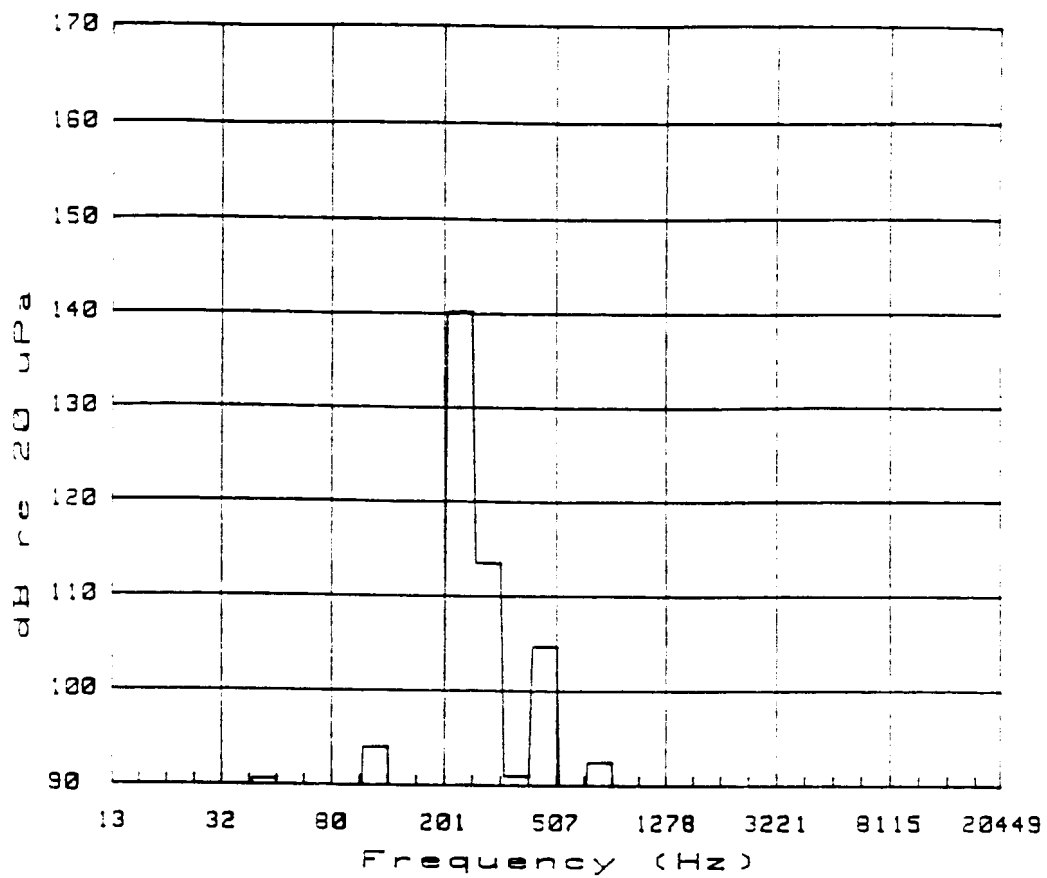


FIG A2.3. The calibration test for the hydrophone. The test signal from the calibrator was 139.8 dB re 20 μ Pa.

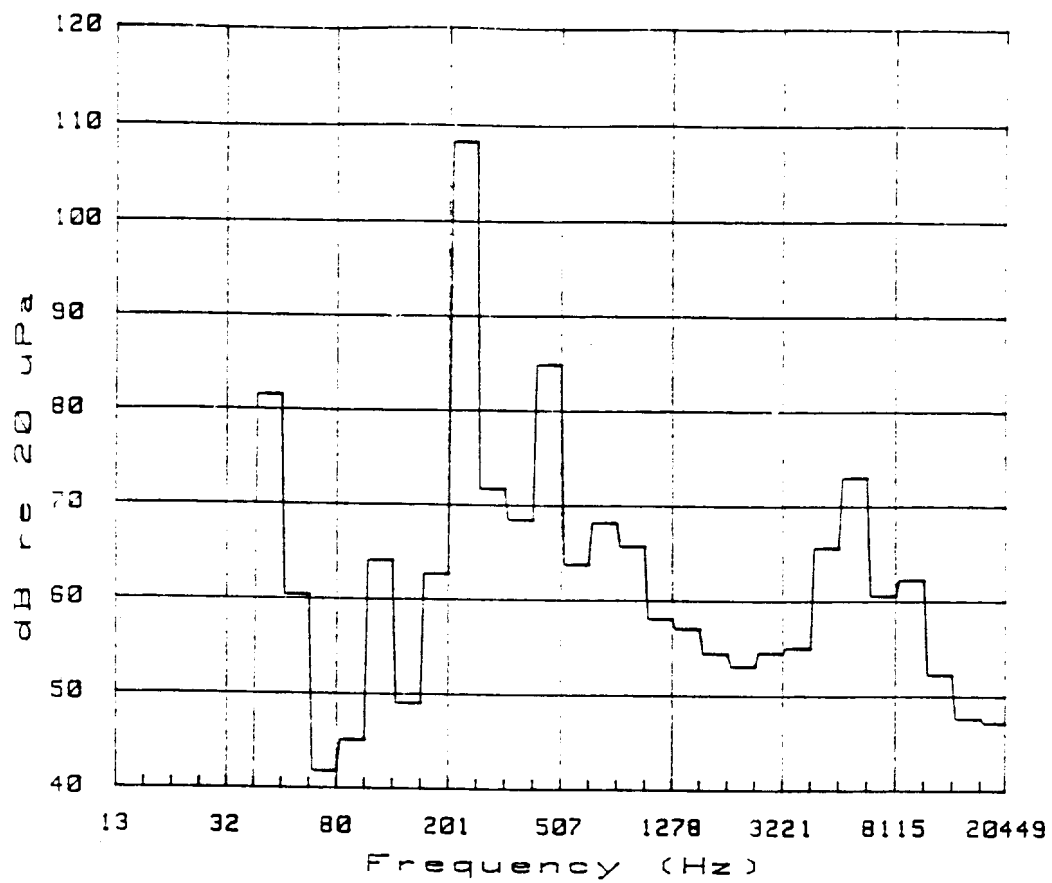


FIG A2.4. The calibration test for the sound level meter. The test signal from the calibrator was 109 dB re 20 μ Pa.

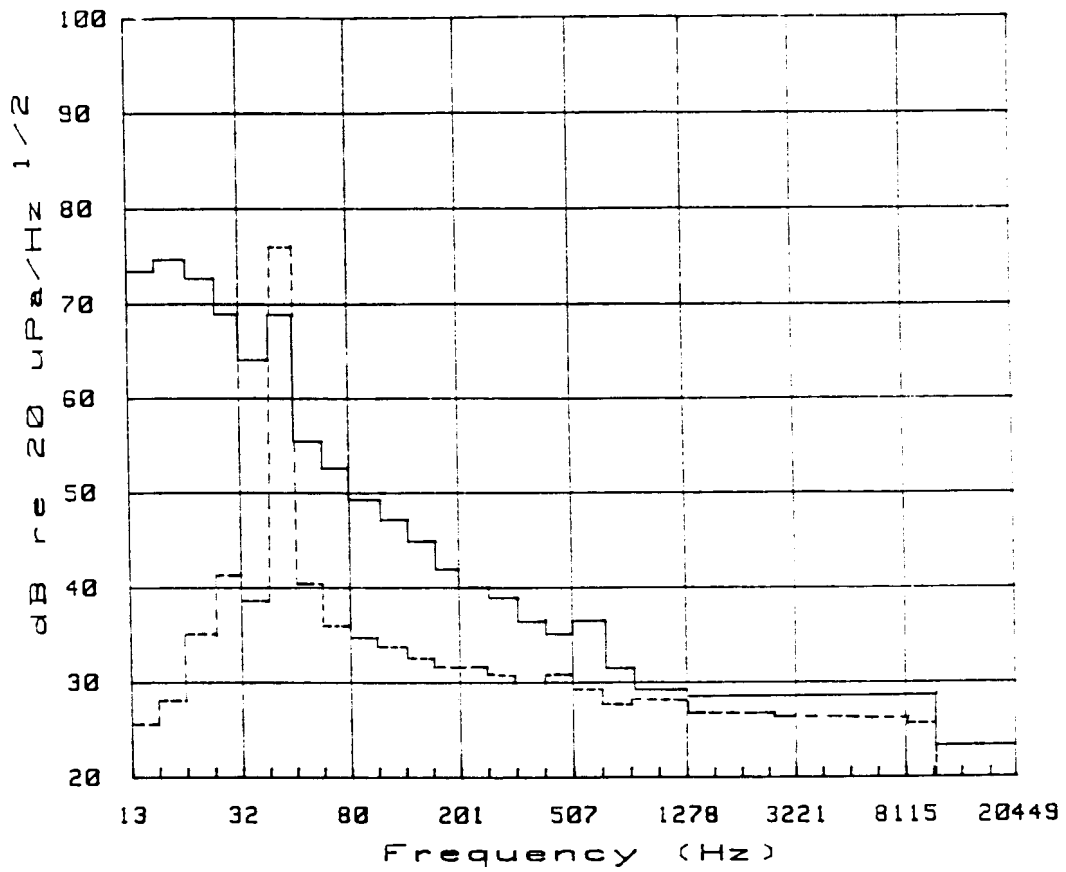


FIG A2.5. The average residual intrauterine SPL of 8 subjects (linear weighted, third-octave analysis, averaged over 32 seconds, bandwidth corrected) (solid line) presented with the SPL produced by the equipment (broken line).

APPENDIX 3

INDEX TO AUDIO CASSETTE

The accompanying cassette contains edited intrauterine acoustic recordings obtained in the process of this study. In order to obtain a fair representation of the original, a good quality tape recorder should be used. The following extracts have been included:

(Start tape)	000
The residual intrauterine sound	002
The intrauterine sound during presentation of the maternal voice	010
The intrauterine sound during presentation of an external female voice	021
The intrauterine sound during presentation of a male voice	031
The intrauterine sound during presentation of a music stimulus	037

ABBREVIATIONS

1F	quiet sleep state in the fetus
2F	active sleep state in the fetus
3F	quiet awake state in the fetus
4F	alert awake state in the fetus
ABR	auditory brain stem response
ACR	auditory cortical response
APR	auropalpebral response
AS	acoustic stimulation
AST	acoustic stimulation test
b/m	beats per minute
C	control
cm	centimetre
dB	decibel
dba	A-weighted decibel
FHR	fetal heart rate
h	hour
HR	heart rate
Hz	hertz
I	interval group, in which the music which had been repeatedly presented during pregnancy was presented during the intervals between sucking
ICU	intensive care unit
KHz	kilohertz
m	metre
M	music period, period during which music stimulation was presented
min	minute
MS	music stimulus
ms	millisecond

NM	novel music stimulus
NST	non stress test
μPa	micro Pascal
PM	prescribed music stimulus
S	sucking group, in which the music which had been repeatedly presented during the intrauterine stage was activated by sucking activity
SE	standard error
sec	second
VS	vibroacoustic stimulation
V	volts
W	watts

GLOSSARY

The following definitions have been compiled from Hassall and Zaveri (1979), Stedman (1976), Apel (1976), Everest (1981), Kinsler et al. (1982), Fowler and Fowler (1969) and Parker (1984). Only the meanings pertaining to the specific use in this document have been described.

A-weighted sound levels:	the assignment of a 'weight' to each frequency level, in accordance with the sensitivity of the human ear to that frequency
acoustic:	relating to sound, hearing
acoustics:	the science of sound
acoustic reflex threshold:	the lowest intensity level of particular frequencies required for the elicitation of the acoustic reflex
acoustic reflex:	a reflex which causes a change in the acoustic impedance of the middle ear system
acoustic stimulus:	sound stimulus as opposed to a vibratory stimulus; stimulus with auditory components as opposed to tactile components
ambient noise:	the pervasive noise associated with a given environment, being usually a composite of sounds from sources both near and distant.
amniocentesis:	transabdominal aspiration of fluid from the amniotic sac
amniotic fluid:	the fluid within the membrane around the fetus
anatomy:	the study of the structure of an organism
anencephaly:	severe defective development of the brain
anterior:	in the front part of

apgar score:	a rating according to specified tests which gives an indication of the well-being of the neonate immediately after birth
asphyxia:	suffocation as a result of impaired absorption of oxygen
articulation:	the harmonics of one note change even during the shortest time in which that note is played and the quality of the very beginning of the note is caused by the manner of articulation or attack in its performance
attenuation:	the reduction or loss in the intensity of sound due to propagation and absorption effects
auditory:	pertaining to the sense of hearing
auditory response cradle:	a crib designed to automatically record aspects of neonatal or infant movement, respiration, etc.
auropalpebral:	blink-startle response of the eyelid
auscultation:	listening to sounds
autism:	severe psychiatric disturbance evident before 30 months of age
autonomic function:	the function of the autonomic nervous system which supplies the body, including the organs
average evoked auditory potentials:	electrical activity of the brain or brain stem in response to sound stimulation which is recorded, amplified, filtered, added and averaged. The components of the electrical activity are waves which may be described with Roman numerals
auditory evoked potentials:	measurements of the electrical activity of the brain or brain stem in response to sound
axon:	a branching process from the nerve cell
band:	range of frequencies between defined limits
bandwidth:	the difference between the frequency limits of a band containing the useful frequency components of a signal
baseline:	average point of reference
beat:	the temporal unit of a musical composition; recurring rhythmic pulse

GLOSSARY

behavioural state:	state of sleep or alertness
bone conduction:	the transmission of sound to the inner ear through vibrations applied to the bones of the skull
borborygmi:	rumbling or gurgling noises produced by movement of gas in the alimentary canal
brain stem:	the midbrain, pons, medulla
brain stem potentials:	measurements of the electrical activity of the brain stem
broad band:	a band with a wide range of frequencies
caesarian section:	birth effected by cutting the wall of the abdomen
cardiotocography:	the measurement of the heart rate
central auditory system:	pathway by which sound is processed beyond the peripheral ear structure
central conduction:	the processing of stimuli through the auditory pathway beyond the peripheral ear structure
cephalic presentation:	position of the fetus with head towards the vaginal canal
cerebral:	relating to the cerebrum
cerebrum:	largest portion of the brain, where consciousness resides
cervix:	lower part of the uterus extending into the vagina
cervical os:	hole in the cervix
cognitive perception:	perceiving as an act distinct from emotion and involving a level of perception more advanced than of basic sensory perception
compromised fetus:	fetus adversely affected as a result of some abnormal occurrence or pathology
conditioning:	the recruitment of a new response to a previously neutral stimulus.
congenital deafness:	deafness existing at birth, either hereditary or due to some influence before or during birth
contraction:	tensioning of the uterine muscles which occurs during labour
cortex:	outer grey matter of the brain
cortical potentials:	measurements of the electrical activity of the cortex
coupling:	the transfer of sound energy from one medium to another

crib-o-gram:	a crib designed to automatically record aspects of neonatal or infant movement, respiration, etc.
cutaneous:	of the skin
decibel:	a comparison of intensities; a sound level is expressed as the (10 x logarithm) ratio of its intensity to that of a reference pressure level
delivery:	birth
dendrite	a short branching process of a nerve cell
dendritic spine:	short spikes on dendrites
Down's syndrome:	congenital chromosomal abnormality associated with mental retardation (Mongolism)
duration:	length of time
dynamics:	a common term for describing loudness in music
early components:	the components of the auditory evoked response which have short latencies (0 msec - 10 msec latency)
effusive otitis media:	inflammation of the middle ear, with collection of fluid
eighth cranial nerve:	auditory nerve
electroencephalography:	the registration of electrical activity of the brain
electrical potentials:	electrical activity of the brain or brain stem which is recorded, amplified, filtered, added and averaged. The components of the electrical activity are waves which may be described with Roman numerals
embryology:	the science of the origin and development of the organism from the fertilisation of the ovum until birth
epidural analgesia:	technique of spinal pain relief
episiotomy:	surgical incision of the vulva to prevent laceration at the time of delivery
equal loudness perception:	the phenomenon of human hearing which results in frequencies of dissimilar intensities appearing to be equally loud
fetal:	relating to the fetus
fetal distress:	distress in the fetus evident in physical signs
fetus:	the developing human from 8 weeks gestation to birth
frequency:	rate of occurrence of vibration

GLOSSARY

full-term:	born at the normal stage of pregnancy, being 37 - 41 weeks gestation
galvanic skin reflex:	direct current electricity produced by chemical action in the skin
general anaesthesia:	loss of consciousness induced by anaesthetic agents
gestation:	the period between conception and birth
habituation:	the gradual attenuation and cessation of response to a repeated stimulus
haemorrhage:	a profuse loss of blood from the blood vessels
harmonics:	the series of frequencies which are multiples of some fundamental frequency, occurring simultaneously with the fundamental frequency in the case of all sounds other than pure tones. These sounds are softer than the fundamental note and create the timbre peculiar to that particular sound.
harmony:	the chordal (vertical) structure of a musical composition in contrast to the melodic (or horizontal) structure
hertz:	the common unit for the measurement of frequency
high-pass filtered noise:	noise subjected to a filter which transmits all frequencies above a given cut-off frequency and substantially attenuates all others
histology:	the science that deals with the minute structure of cells, tissues and organs in relation to their function
hydrodynamic:	the forces acted on or exerted by liquids
hydrophone:	microphone designed for use in a liquid medium
impedance:	the ratio of the sound pressure on a given surface to the sound flux through that surface
incubator:	an enclosed crib for the infant, providing proper temperature, humidity and oxygen
inferior colliculus:	part of the midbrain
intensity:	a measure of the rate of sound energy passing through a given unit surface area
interval:	the distance in pitch between two tones
intrauterine:	within the uterus

labour:	the process of expulsion of the fetus from the uterus at the termination of pregnancy
late components:	the components of the evoked auditory response which have slow latencies (50 msec-500 msec)
latency:	the period of time between the presentation of a stimulus and the moment of response
latent phase of labour:	early stage of labour, before active labour
lateral-stimulus presentation:	the presentation of a stimulus from the side position
linear:	the simplest noise measurement which is independent of frequency, disregards the variation with time, and therefore ignores the two factors which are known to effect subjective reaction to noise measurements
localisation:	detection of the direction from which a sound emanates
meconium staining:	the sterile intestinal discharges of the fetus which are a sign of fetal distress
medial geniculate body:	part of the auditory pathway in the brainstem
melody:	succession of musical notes arranged in horizontal order, as opposed to harmony which involves simultaneous sounding of notes
melodic:	pertaining to melody
membrane:	the amniotic sac around the fetus
mesencephalon:	same as the midbrain
micro Pascal:	a millionth unit of pressure equal to the pressure resulting from a force of one newton acting uniformly over an area of one square metre
midbrain:	upper portion of the brainstem
middle latency:	the aspects of auditory evoked potentials which have latencies of medium length (10 msec -50 msec)
mode:	a series of notes with prescribed intervals between them
Moro reflex:	startle reflex involving the extension and flexion of limbs
myelination:	the acquisition or development of a myelin sheath around a nerve fibre
narrow band:	a band with a narrow range of frequencies

GLOSSARY

neonatal:	relating to the newborn
neonate:	newborn up to the age of one month
neurological arousal state:	state of arousal or sleep
neuromotor:	nerves and muscles involved in movement
neuron:	nerve cell
non stress test:	the measurement of the fetal heart rate with no stimulation provided
non-nutritive nipple:	an artificial pacifier shaped as a nipple
occiput:	the back of the head
oculomotorsystems:	nerves and muscles involved in moving the eye
operant learning:	the modification of behaviour as a result of a positive or negative reinforcement
orientation:	detection of the direction from which a sound emanates
oscillation:	to-and-fro movement
ossicular chain:	the chain of the incus, malleus and stapes
otitis media:	inflammation of the middle ear
oto-acoustic emissions:	cochlear echoes
outcome measures:	resulting condition
oxytocin stress test:	measurement of the heart rate during administration of the oxytocin drug
pathology:	the study of disease
pathological:	pertaining to pathology
perinatal:	period immediately before, during and immediately after birth
perinatal morbidity:	disease around the immediate time of birth
peripheral auditory mechanisms:	the external, middle and inner ear structures
phonetic:	corresponding to vocal speech sound
phonocatheter:	a hollow tube with a diminutive microphone housed in its tip for recording sounds
pink noise:	a specified range of frequencies in which the noise intensity is inversely proportional to frequency, to give constant energy per octave
pitch:	frequency level
postprandial:	after eating
postnatal:	period immediately after birth

premature:	born before 37 weeks gestation
prenatal:	before birth
pressure transducer:	equipment designed for the measurement of pressure
preterm:	born before 37 weeks gestation
proprioceptors:	one of a variety of sensory end organs
psychophysiology:	the science of the relation between psychological and biological function
pure tone:	a sound having a fundamental frequency with no harmonics
reflex:	innate, involuntary response
rehabilitation:	restoration through therapy
residual:	baseline, background
resonance:	resounding of vibration
rhythm:	the movement of music across time, commonly understood to mean the repetitive beat or the individual timing of a note or group of notes
rhythmic dyadic interaction:	interrelated communication between two people
rupture of membranes:	the tearing of the amniotic sac
startle response;	a response indicating sudden fright
scale:	a series of notes with prescribed intervals between them
sensory processing:	interpretation of sensory input within the brain
sine wave:	commonly understood to mean a pure tone
sound pressure level:	a term commonly understood to mean loudness; a value in decibels equal to twenty times the logarithm to the base 10 of the ratio of the pressure of the sound under consideration to a reference pressure
spacially-coordinated response:	a movement response in the direction of the location of a stimulus
spectral content:	the amplitude of the frequency components of a complex wave form throughout the frequency range of the wave form

GLOSSARY

spectrum analysis:	the measurement of the amplitude of the frequency components of a complex wave form throughout the frequency range of the wave form
square wave:	a tone involving an oscillation, the amplitude of which shows periodic discontinuities between two values, remaining constant between jumps
stapedial reflex:	reflex involving the stapes bone, which protects the inner ear from loud sounds
state:	arousal level
synapses:	the functional membrane-to-membrane contact of the nerve cell with another nerve cell
systolic:	related to the contraction of the heart
tachycardia:	rapid beating of the heart
term:	born at the normal stage of pregnancy (37-41 weeks)
thresholds of hearing:	the minimum perceptible intensity level of a tone which can be detected at each frequency over the entire range of the ear and the maximum level of intensity before the experience of pain
timbre:	the quality of a sound determined by the harmonics coinciding with the fundamental frequency
timing:	a musical term commonly used to describe metre, tempo, duration, etc.
tone:	commonly used as a musical term to describe the sound of a definite pitch
tone colour:	the quality of a note determined by the harmonics which occur with the fundamental frequency
trimester:	the period of gestation is divided into three stages, each lasting three months, which are referred to as trimesters.
ultrasonic imaging:	creating a visual image by means of extremely high frequency sound waves
uterus:	the womb
vagina:	the genital canal in the female extending from the uterus to the vulva
vascular:	of vessels carrying blood
vertex:	the crown of the head

vestibular organs:	organs of the inner ear involved in the detection of balance
vibration:	continuous rapid movement, the continuous displacement and returning to rest of a body (solid, liquid or vapour) which would continue indefinitely if it were not for friction, through which energy is transferred away from the source by progressive sound waves
vibroacoustic stimulus :	a stimulus with vibratory and acoustic components
viscous:	intermediate between solid and fluid, flows with difficulty (such as treacle)
wave:	a component of the electrical activity recorded from the brain or brainstem, usually described by means of a Roman numeral
white noise:	random noise that has a constant energy per unit bandwidth at every frequency in the range of interest
wide band noise:	noise exhibiting a wide range of frequency

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