The Fetus in Utero: The Ability to Hear and React to Music

An Honors Thesis (HONR 499)

by

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Abstract

It is intriguing to consider to what extent a fetus can hear and react to sounds present in the environment (Gerhardt & Abrams, 2000). According to Armitage and his coworkers, “the auditory experience of the fetal mammal may be considerably more extensive, more varied, and...possibly of greater postnatal significance than has been believed (Childs, 1999, p. 107). The fetus has a spectacular range of senses and lively emotions expressed through interactions and body language (Chamberlain, 2003) and is considerably more sophisticated and sensitive than previously believed (Winter, 1994).

This research explores the ideas of the development of the fetal auditory system, the ability of a fetus to hear in utero, and if a fetus can react to music, whether in a positive or negative manner. The potential positive and negative effects of these stimulations on the fetus in utero and after birth and beneficial interventions are examined. This thesis is a compilation of current research that can provide insight to the many questions that expecting parents often have regarding these topics before, during, and after pregnancy.
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Introduction

Mankind has always been captivated by concepts that cannot be seen or fully understood in a scientific manner, the fetal environment being one of those. Cultures have always studied and held their beliefs and traditions in regards to the fetus in utero. It was not until the 1980s with advancements in scientific technology that scientists began to analytically investigate fetal sensory sensitivity (Van Chi Lee, 2010). As intrigue continues to rise, research is revealing the true capacities of a fetus in utero, its ability to learn from its parents’ environment, and its impeccable sensitivity and responsiveness to auditory stimuli as a result of its precocious sensory development (Chamberlain, 1999).

Auditory Development

Development of the fetal auditory system begins during the embryonic phase, around the tenth to fourteenth day after conception (Yan Chi Lee, 2010). Initially, the homogenous mass of blastocyst cells differentiates into the three primary germ layers of ectoderm, mesoderm, and endoderm; the ectoderm is the layer from which the internal and external ears are derived (Yan Chi Lee, 2010). By the fourth week of gestation, the otocyst divides into two lobes, one forming the cochlea and the other forming the labyrinth (Yan Chi Lee, 2010). Next, the cochlea is fully coiled and the cochlear duct is well formed by the ninth week of gestation (Yan Chi Lee, 2010). The tectorial membrane primordium, a factor responsible for the regulation of growth and arrangement of stereocilia, is evident by the tenth week (Yan Chi Lee, 2010).
The neural basis of hearing initiates around week fourteen within the cochlear hair cells as transduction channels, in the tips of stereocilia, transport cations in response to mechanical displacement of the organ of Corti (Yan Chi Lee, 2010). At twenty weeks, the tunnel of Corti opens, but due to its high threshold and poor discriminative properties, a fetus cannot respond to acoustic stimulation for a few more weeks (Yan Chi Lee, 2010). Circa weeks 23 to 25, a fetus begins to actively listen (Whitwell, 1999) and indicate sound preferences (Foster & Verny, 2007) as the cochlea reaches adult size, though the cochlea will continue to mature and develop until week 30 of gestation (Yan Chi Lee, 2010). As mature synapses are also forming during this period, most formal programs of prenatal stimulation are designed to begin nearing the third trimester (Whitwell, 1999).

Following myelination, which begins during week 26 to 28, and rapid, synchronized conduction of auditory impulses in the cochlear nerve and brainstem (Yan Chi Lee, 2010), auditory evoked responses and acousticomotor reflexes indicate the onset of complete human auditory function by the start of the third trimester (Gerhardt & Abrams, 2000). At this time, as a sound discriminating mechanism becomes fully operational, a fetus can detect changes in auditory stimuli (Anderson, 2005) and discern rhythm, intonation, and other speech patterns of its mother’s voice (Foster & Verny, 2007).

Research

Though there is extensive knowledge regarding the development of the fetal auditory system, the ability of a fetus to hear in utero is still under dispute. David Mellow, a prominent professor at Massey University in New Zealand, undertook a research study in which the results
contraindicated the views of many medical experts (Carbonell, 2005). The research suggested that there is little point to playing music or talking to the fetus as babies in utero are in a “deep sleep” until they are born; Dr. Mellow and his colleagues believe there are chemicals in the fetus that are produced by its brain and the placenta that actively keep it asleep (Carbonell, 2005). Despite the facts a fetus’ senses are often quite developed upon birth, a fetus can react to sound or move away from a painful stimulus, such as a needle, and input from sense organs like the ears affect the brain, Dr. Mellow postulates that the fetus cannot consciously hear or react to stimuli (Carbonell, 2005).

Speculation will always surround circumstances that involve subjects with whom one cannot verbally communicate. In spite of early studies reporting that the fetal environment sound level was insufficient for hearing (Gerhardt & Abrams, 2000), researchers have continued to pursue answers through studies employing ultrasound techniques; such studies have shown that a fetus can hear and respond to pressure through touch long before birth (Turner, 2010). There are many factors that determine how well a fetus can hear in utero, such as: the transmission of sound into the fetal inner ear, the frequency content, the attenuation of external sounds due to the tissue and fluid surrounding the fetal head, the level of internal noise, and the sensitivity of the fetus’ hearing at the time of the auditory stimuli (Gerhardt & Abrams, 2000).

Two main hypotheses have arisen to describe the route that exogenous sounds travel in order to reach the fetal cochlea: hearing via bone conduction and acoustic stimuli passing through the fluid-filled external auditory canal and middle ear to reach the inner ear (Gerhardt
& Abrams, 2000). As a result of several studies, many scientists believe that sound transmission through the outer and middle ear system is likely to be rendered less effective as the mechanical aspects of the ear are greatly diminished due to the presence of fluids that fill the external canal and middle ear cavity (Gerhardt & Abrams, 2000). A study designed by Dr. Gerhardt and Dr. Abrams from Florida University that compared the effectiveness of these two popular hypotheses concurred (2000).

In their study, an underwater microphone, also known as a hydrophone, was placed inside the cervix or upper portion of the uterus after an amniotomy, artificial rupture of membranes, had been performed (Gerhardt & Abrams, 2000). This device measured the sound pressure levels produced by a speaker near the mother’s abdomen, and the recorded levels were then compared to the pressure levels detected with a standard microphone positioned between the speaker and the mother’s abdomen (Gerhardt & Abrams, 2000). During the next stage of the study, the process was repeated, but the hydrophone was placed in a pocket of fluid near the fetus’ neck instead (Gerhardt & Abrams, 2000). Induced by a sound field in the amniotic fluid, skull bone vibrations were responsible for generating a sound field within the fetal cranial cavity, including the brain and cerebral spinal fluid; the sounds were then relayed to the inner ear through fluid communication channels that connect it to the cranial cavity (Yan Chi Lee, 2010). Sound transmission through bone conduction presented as the most effective means for fetal hearing as it occurs in a fluid-filled environment, similarly to how humans hear underwater (Gerhardt & Abrams, 2000). A surge in curiosity regarding this topic has led to an increase in evidence that the intrauterine environment is acoustically rich and that a fetus is capable of hearing and responding to sound in the womb (Moon & Fifer, 2000).
The fetal sound environment is composed of a variety of internally generated noises, such as those from the maternal respiratory, intestinal, and cardiovascular activity; these sounds provide a background noise above which maternal vocalizations and sounds originating from her environment emerge (Gerhardt & Abrams, 2000). Through carefully controlled human studies, the subjective experiences of mothers regarding fetal movements in response to stimuli have been shown to coincide with simultaneous changes in fetal heart rate and sleep state (Gerhardt & Abrams, 2000). Common methods, like cardiotocography and ultrasound scanning (Van Chi Lee, 2010), have been used to measure fetal responsiveness to external stimuli by analyzing characteristics such as pulse rate, reflexive behavior or movement, and activity or inactivity (Gerhardt & Abrams, 2000).

A popular adjunct to the traditional fetal nonstress test is the use of fetal vibroacoustic stimulation; its objective is to recognize a stimulus-linked increase in fetal activity by analyzing cardioacceleration (Abrams & Gerhardt, 2000). Obstetricians often use an electronic artificial larynx (EAL), a small handheld vibroacoustic stimulator, and place it on the mother’s abdomen near the diaphragm for a few seconds (Abrams & Gerhardt, 2000). When activated, the EAL produces an acoustic signal in the uterus and causes fetal excitation (Abrams & Gerhardt, 2000). In a study implemented by Dr. Gagnon, though fetuses between 26 to 32 weeks of gestation did not show a change in gross fetal movement upon EAL stimulation, fetuses 33 to 40 weeks of gestation did show an increase in gross fetal movement, as well as tachycardia, after five seconds of stimulation (Abrams & Gerhardt, 2000). Altered breathing activity with a decreased rate and irregular rhythm occurred in fetuses aged 33 to 40 weeks (Abrams &...
Gerhardt, 2000). Not only does the fetus experience cardiac changes to vibroacoustic stimulation, but to its mother’s voice as well.

In a study performed by Dr. DeCasper and his colleagues, mothers during weeks 33 to 37 weeks of gestation were asked to recite a rhyme aloud each day (Krueger, Davis, Quint, & DeCasper, 2004). At 37 weeks, the fetuses were exposed to the maternal rhyme and to a control rhyme while their cardiac reactions were analyzed (Krueger et al., 2004). A small, brief cardiac deceleration was elicited while listening to the maternal rhyme, but not when listening to the control rhyme (Krueger et al., 2004). It has been theorized that this small, brief deceleration is an attentional response in order to enhance stimulus intake, whereas an acceleration would be a defensive response in order to limit stimulus intake (Krueger et al., 2004). Around the seventh and eighth month, regardless of content, the mother’s voice has a calming effect as a fetus’ heart rate tends to slow whenever the mother is speaking (McCarthy, 1998).

In 1999, Dr. Elliot identified how the mother’s voice is the most important sound as it brings pleasure to the fetus, and in reciprocation, the fetus begins to interact with and respond to her voice (Foster & Verny, 2007). In 2003, Dr. Kisilvsky and his colleagues investigated the influence of in utero experiences on the fetus’ ability to recognize and differentiate between its mother’s and a strange woman’s voice (Yan Chi Lee, 2010). In the study, the mothers laid in a semi-recumbent position for a six-minute period, while the fetuses were presented one of two voice conditions, either the mother or a strange woman’s voice telling a story, through a speaker held ten centimeters above the maternal abdomen (Yan Chi Lee, 2010). Throughout
the process, fetal heart rate was monitored while body movement was video-recorded (Yan Chi Lee, 2010). The results showed that near-term fetuses are able to discriminate between a mother’s voice and a stranger’s voice as there was an increase in heart rate when exposed to the tape of their mother’s voice and a decrease in heart rate when exposed to the stranger’s voice (Yan Chi Lee, 2010). Even after birth, the newborn is still able to recognize and even prefer its mother’s voice (Childs, 1999).

Dr. Fifer, a professor at Columbia University, developed a study in which doctors gave day-old newborns pacifiers that were connected to tape recorders, and depending on the sucking pattern of the newborn, the pacifier either turned on a tape of its mother’s voice or that of a strange female’s voice (McCarthy, 1998). Within ten to twenty minutes, the newborns learned how to adjust their sucking pattern in order to turn on their mother’s voice (McCarthy, 1998). Dr. Fifer stated this upon analyzing the results, “This not only points out a newborn’s innate love for his mother’s voice but also a baby’s unique ability to learn quickly” (McCarthy, 1998, p. 2). Studies have also shown that newborns will change their sucking patterns in order to turn on tape recordings of people speaking their mother’s language rather than tapes in a foreign language (McCarthy, 1998).

It is important to understand though that the newborns are likely recognizing the rhythm and melody of their native language, rather than the individual words (McCarthy, 1998). Now all of this does not mean that a mother needs to converse with her unborn child in order to give it a head start in language development, but rather to understand that her fetus is receiving all of the necessary information it needs just by listening to her and the environment
(McCarthy, 1998). Doctors are finally understanding that babies begin to engage many of their senses, hearing being the most developed of them all (Whitwell, 1999), and learn about the world around them before they are even born (McCarthy, 1998).

Rather than being born a “blank slate,” a newborn has remarkably extensive experiences regarding its surrounding environment as it seems to respond distinctly to sounds in which it had reacted to in utero (Partanen, Kujala, Tervaniemi, & Huotilainen, 2013). For instance, the newborn can discriminate its mother’s voice from that of a stranger’s, distinguish between its mother’s native language versus a foreign language, and even recognize familiar sounds and melodies from the prenatal environment (Partanen et al., 2013).

Furthermore, a fetus can differentiate among and demonstrate a musical preference among diverse types of music (Gerhardt & Abrams, 2000). Music and singing provide the same benefits as speaking, but with added stimulation from rhyme, rhythm, and melody (Fink, 2012). In studies analyzing the ability of music and the singing voice to penetrate the uterus and impact the fetus, fetal movements became livelier during the exposure (Gerhardt & Abrams, 2000). Depending on characteristics of the music, such as volume, rhythm, and how suddenly it crescendos, and the state of the fetus during exposure, the fetus typically shows a response through an alteration in heart rate (Gerhardt & Abrams, 2000). The tempo of a musical piece has been shown to have a prominent effect on the fetal heart rate; in pieces with a faster tempo, a quicker heart rate is typically noted, while a slower tempo tends to elicit a slowing of the heart rate (Martens, 2013).
By utilizing actocardiographs, Dr. Al-Qahtani designed a study to examine the alteration of fetal behavior when exposed to music and voice, and whether the fetal response to voice differs from music (Al-Qahtani, 2005). Via a headphone on the maternal abdomen near the fetal head, twenty full-term fetuses were exposed to guitar music and a female voice-recorded nursery rhyme in random order with each stimulus being played three times for fifteen seconds (Al-Qahtani, 2005). In response to both the music and voice stimuli, the fetuses displayed a change in behavior in conjunction with increased motor responses and heart rate acceleration (Al-Qahtani, 2005). Interestingly though, data showed no significant difference in the fetal responses between the music and voice stimuli (Al-Qahtani, 2005). Music can also have a profound calming effect.

As mentioned earlier, musical pieces that have a slower tempo tend to elicit a decrease in fetal heart rate; studies have also shown that such pieces can also lead to a decreased respiratory rate and a more relaxed fetal state (Schwartz, 1998). As a mother softly sings to her child while touching her abdomen, she can feel the baby respond as it reacts to the vibrations of her voice; not only does this have a calming effect on the fetus, but it does on the mother as well (Fink, 2012).

Interventions

Considering music has profoundly affected virtually every culture spiritually, mentally, emotionally, and physically, Dr. Odent, a physician in California, believes that throughout history women have had this instinctive need to sing to their unborn babies (Whitwell, 1999). As a mother interacts with her fetus, it is essentially having its first cultural and language
lessons before it is even born (Whitwell, 1999). Music prepares the fetus to listen to, produce, and integrate language sounds as it utilizes many of the same elements as language, such as pitch, rhythm, intensity, and timbre (Whitwell, 1999). According to Dr. Odent, “Music can thus be considered a pre-linguistic language which is nourishing and stimulating to the whole human being, affecting body, emotions, intellect, and developing an internal sense of beauty, sustaining and awakening the qualities in us that are wordless and otherwise inexpressible” (Whitwell, 1999, p. 256). As evidenced by the increasing amounts of studies and their surmounting results, “music is destined to play a more active role in the future of medicine” (Whitwell, 1999, p. 255).

Singing and talking to an unborn baby fosters and promotes an early bond and enables parents to feel connected; it also allows fathers to feel more actively involved in the pregnancy (McCarthy, 1998). Health professionals are in a privileged position to communicate with mothers and their babies from conception to birth (Chamberlain, 2003), and it is imperative that proper instruction and explanation is provided so that a mother understands the many components of her pregnancy and understands the significant role she plays in her baby’s life. With this knowledge, expectant mothers can confidently apply their tenacity for ensuring optimal fetal development by providing a stimulating and healthy fetal environment (Jarvis, 2014).

In order to promote confidence and self-respect, mothers should be taught how their body is “set-up” to allow the fetus to hear her voice amongst the other internal sounds present, and the benefits associated with this interaction (Krueger, 2001). Due to the vestibular
stimulation of the fetus by movement of the maternal diaphragm and associated muscles as she speaks, the efficiency to which the fetus hears is affected by the position of the mother; an upright position enhances the presence of her voice versus a lying position that lessens the chance of valuable fetal hearing (Moon & Fifer, 2000). Equally as important as the mother’s position is the content of the auditory stimulus being provided.

In addition to understanding how styles of music can elicit unique fetal responses, mothers need to be aware that content of auditory stimuli has a lasting impression on the fetus. As a mother takes her cultural beliefs and traditions into consideration, a mother must also remember that her baby associates emotions and attitudes to the stimuli in which it is hearing (Childs, 1999). These associations made during the prenatal stage of a baby’s life can nurture a sense of security and familiarity upon birth as a pre-recorded tape can be played during labor (Winter, 1994). However, far exceeding all other sounds, the maternal heartbeat is the most vital for the baby.

The majority of new mothers tend to exhibit a natural and instinctive preference for holding their newborn on the left side of their chest near the heart, and for good reasons (Schwartz, 1998). It is believed that the newborn associates the mother’s heartbeat to the feeling of well-being assumed to exist in utero, and that the rhythm of the heartbeat provides a sense of security due of its promise of repetition and continuity (Whitwell, 1999). With this insight, the sound of a mother’s heartbeat has been implemented into multiple health practices.
In several experiments, it has been found that premature babies who are thrust into intensive care thrive when hearing sounds they remember from the womb (Chamberlain, 1999). In these experiments, selected intensive care nurseries played recordings of heartbeats, while other nurseries did not; the results were astonishing as the babies exposed to the heartbeats gained weight more rapidly than those who were not (Chamberlain, 1999). In like manner, the playing of intrauterine sounds and music has also shown to have positive effects on intubated, monitored, and agitate premature newborns; these babies improved in behavior, had a significant increase in oxygen saturation, and had decreased levels of agitation (Chamberlain, 1999). These and additional studies incorporating sound and music therapy into a premature newborn’s treatment plan have shown an average of a three to five day earlier discharge from the neonatal intensive care unit (Schwartz, 1998). Earlier discharges not only greatly benefit the growth and development of these babies, but overtime, they may also lead to cost savings, which has always been an issue for modern society (Schwartz, 1998). Like with any health treatment and intervention, there are warnings and precautions one must heed.

Key questions addressing the effects of noise on the fetus remain to be fully answered and understood, such as appropriate duration, frequency, intensity, and work exposure. Some researchers believe that increasing fetal auditory stimulation beyond what is provided by the ambient sound level is not warranted as it could be detrimental to the fetal auditory development; thus, they recommend against using sound enhancement devices like speakers or headphones to present sound to the baby in utero (Moon & Fifer, 2000). Caution must also be taken in preventing frequent, intense, sustained noises or impulses as changes in the fetus’ sleep/wake cycle and damage to the auditory system can ensue (Moon & Fifer, 2000). In a
study designed by Dr. Gerhardt, researchers evaluated and compared the integrity of cochlear hair cells through the use of electron microscopy in non-exposed and noise-exposed fetuses (Gerhardt & Abrams, 2000). Upon examination, both the inner and outer hair cells of the noise-exposed fetuses were damaged and scarred (Gerhardt & Abrams, 2000). Though it is highly unlikely that a pregnant mother would experience the magnitudes of exposure used in this study and the likelihood that significant fetal hearing loss from noise exposure of its mother is minimal, a conservative approach should be taken to avoid overexposing the immature fetal auditory system to sustained, intense noise levels (Gerhardt & Abrams, 2000).

In relation, a mother must also be cognizant of the noise levels within her environment, like the workplace for example, and there is concern as to whether or not guidelines should be established for pregnant women in the workplace (Abrams & Gerhardt, 2000). Regardless of guidelines, mothers can take appropriate, preventative measures to reduce not only work-related exposure, but often overlooked entertainment exposure as well (Jarvis, 2014). For instance, a mother could take maternity leave from work, watch a movie at home rather than in a theater, avoid concerts, and maintain lower volume levels when listening to music (Jarvis, 2014).

In addition, as there are no Occupational Safety and Health Administration regulations addressing fetal exposure limits or guidelines regulating noise exposure in intensive care nurseries (Abrams & Gerhardt, 2000), healthcare professionals must be responsible for researching and understanding how noise exposure levels can affect a fetus and newborn. Furthermore, healthcare professionals must be mindful of aiding parents to keep proper
perspective. Whether or not certain in utero stimuli like music and talking provides the baby a head start in education or language learning has not been fully proven, and parents need to be cautious of not placing too much emphasis on achievement at such an early age (Murkoff, 2002). Parents need reassurance that they are providing their baby with all kinds of experiences as the baby is with them throughout the day’s activities; these varieties in experience allow the fetus to be a part of the daily human life, complete with laughing, crying, joy, and determination (Childs, 1999).

Conclusion

With this knowledge, health practitioners and parents can improve their understanding of normal sensory capabilities, learn to promote enriched prenatal environments, and plan interventions (Foster & Verny, 2007). Provided education from practitioners, parents can begin to understand that anything where they engage with their unborn babies is welcomed and encouraged as this period from conception to birth is a critical period for the development of every baby (Carbonell, 2005). An intimate, nurturing relationship is being formed between the child and the parents and has lifelong consequences. In essence, parents can reach new heights of fulfillment in parenthood with a growing wealth of knowledge and a reverence for the sentience of their child (Chamberlain, 2011). Beginning with life in utero, unborn babies need to be recognized for the complex being they are, well-endowed for participating in the world around them (Chamberlain, 2003).


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