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8 Emergence of sound and music perception

‘Let’s start at the very beginning. A very good place to start . . .’ So go the opening lyrics of Rodgers and Hammerstein’s ‘Do Re Mi’ in The Sound of Music (Wise, 1965). In previous chapters, we have described the auditory system and melody and rhythm perception in the mature adult. In the present chapter, we retrace our steps to the very beginning to explore the emergence of hearing and music perception before birth and in infancy. This chapter is divided into two sections. The first part explores the development of hearing before birth and presents some of the main findings in the literature on fetal and newborn responses to auditory stimuli, focusing on responsiveness to the human voice and music. This will require some discussion of what sounds are available to the fetus before birth, and the methods by which we have reached these conclusions. In the second part of the chapter, we explore music perception in the first year of life. Throughout, we describe research procedures in some detail, as readers are often curious as to how studies are carried out during the prenatal period and with young infants.

Part One: Auditory capacities before birth and in the newborn

Perhaps no period of human development is as shrouded in mystery as the months between conception and birth. The course of prenatal auditory development, in particular, is a relatively new area of study and ideas about what the fetus can hear in utero have undergone significant changes. In the early 1900s, it was commonly assumed that humans had little or no auditory sensitivity at all before birth. Expectant mothers’ reports about movements of the fetus in response to loud environmental sounds were routinely met with skepticism. Gradually, however, scientific papers began to corroborate these anecdotal reports. In an early study, Sontag and Wallace (1935) devised a sort of stylus recording device out of inflatable sacks resting against the abdomen, attached to four pens that recorded changes in the shape of the abdomen. When a wood block resting against the woman’s stomach was struck loudly, the researchers noted corresponding movements in the contour of the abdomen. Observing this, they inferred that the fetus responds to external sound or vibration before birth. With new technological

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advancements, much more precise and reliable methods have been devised to study auditory capacities before birth.

Methods for studying fetal responsiveness to sound

One way to examine the auditory capacities of the fetus is to introduce auditory stimuli into the intrauterine environment and monitor any corresponding fetal responses. Several techniques can be used to present sound to the fetus. In the airborne mode, sounds are played via loudspeakers placed near to the mother, usually at a distance of about 1 to 3 feet. In the air-coupled mode, sound is transmitted through loudspeakers or headphones placed directly on the mother’s abdomen, sometimes cushioned by a foam ring to reduce distortion created by direct contact with the skin. In the vibro-acoustic mode, a vibrating device such as a tuning fork or a voice simulator is placed directly on the maternal abdomen.

To determine whether the fetus can detect these sounds, motor responses and physiological changes in the fetus are carefully monitored. Motor responses, such as an increase or decrease in fetal limb movements or a ‘startle’ reflex, can be observed through real-time ultrasound scanning. Physiological changes, such as a change in fetal heart rate following presentation of sound, can also be tracked using fetal tocographs (heart monitors) and other monitoring devices. Researchers rarely rely on maternal reports of fetal movements as the sole measure of fetal responses. Women may perceive 27 to 75 percent fewer fetal body movements than are observed in ultrasound scanning (Kisilevsky, Killen, Muir, & Low, 1991).

Studies employing some of the methods described above suggest that human auditory functioning begins about 3 months before birth. While full-term infants are born at 38 to 42 weeks gestational age (or GA), fetuses already respond to sound by about 25 to 28 weeks, as indicated by an increase in fetal heart rate or fetal movements in response to sound or vibration (e.g., Kisilevsky & Low, 1998). Cortical potentials (rapid fluctuations in brain activity) in response to auditory stimuli have also been detected in preterm infants delivered at only 25 weeks GA (Starr, Amlie, Martin, & Sanders, 1977). The structures of the auditory system, as outlined in chapter 3, are well developed before birth. In particular, the development of the cochlea progresses at a rapid rate: by only 8 to 9 weeks GA the cochlea is fully coiled, and the hair cells begin to differentiate at around 10 to 11 weeks GA (Pujol & Lavigne-Rebillard, 1985). The development of the cochlea is completed by about 30 weeks GA (Pujol, Lavigne-Rebillard, & Uziel, 1990), but cochlear functioning begins some weeks before this, as suggested by the aforementioned studies.

Internal and external sounds in the intrauterine environment

Sounds in the intrauterine environment arise from two sources. Internal sounds originate from inside the mother’s body, such as the mother’s breathing,
abdominal gurgles and other digestive sounds (collectively referred to as ‘borborygmi’), vascular activity, and heartbeats, as well as similar biological sounds originating in the fetus. External sounds originate from the environment outside the mother’s body such as external voices, music, ringing telephones, and traffic noise. The maternal singing and speaking voice is both internal and external in source, as it originates internally but is also transmitted as an airborne sound.

Early recordings of intrauterine noise levels obtained with microphones inserted into the uterus yielded internal noise readings of about 72 to 96 decibels (dB) (e.g., Lecanuet & Granier-Deferre, 1993). Seventy decibels is comparable to the hum of a noisy car engine or vacuum cleaner, and 90 dB would be four times as loud (as decibels correspond to a logarithmic scale, as explained in chapter 3). It was therefore assumed that even if the auditory system were already functional, external sounds such as music and voices would be masked or completely obscured by internal sounds. However, early recording methods were not adapted to address fluid impedance. Findings from more recent studies using equipment such as hydrophones (designed to detect sound in underwater environments) suggest a much quieter intrauterine sound environment. These readings range from about 28 to 65 dB, with wide variability varying with the placement of the recording device, time of day, activity level of the fetus, and other factors (Lecanuet & Granier-Deferre, 1993; Querleu, Renard, Boutteville, & Crépin, 1989, p. 412). Twenty decibels is comparable to the sound level of rustling leaves and 65 dB is the approximate loudness of conversational speech – thus the fetus is most likely exposed to a much richer repertoire of external sounds than previously thought.

Quality of external sounds in the intrauterine environment

As might be expected, one important variable affecting the quality of transmitted external sounds is amplitude. External sounds must be fairly loud to reach the fetus, as they must pass through the maternal abdominal skin and be transmitted through the uterine tissue and fluid. This can lead to some sound attenuation (i.e., loss of strength of the auditory stimulus, or the opposite of amplification) so the sound reaching the fetus is weaker than the original source.

In general, external speech presented in airborne mode at a normal conversational level of about 60 dB and external music presented in airborne mode at about 80 dB (a rather loud listening level) can penetrate through the maternal tissue and emerge above the intrauterine noise level (Querleu, Renard, Versyp, Paris-Delrue, & Crépin, 1988; Woodward, 1992). However, the quality of the sound reaching the fetus also depends on the level of internal noise, which varies with the mother’s level of activity. Internal noises such as abdominal gurgling following a large meal, or cardiovascular sounds and movement of amniotic fluid during physical activity, may mask external sounds. If the mother attends a concert following a hearty dinner, or listens to

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music while exercising, high internal noise levels may be competing with music from the external environment!

Another variable mediating degree of sound attenuation is frequency. In general, high-frequency sounds are subject to greater attenuation via maternal tissue than low-frequency sounds while lower-pitched external sounds are more efficiently transmitted to the fetus. In effect, the abdominal wall acts as a ‘low-pass filter.’ Therefore, musical tones up to 250 to 300 Hz range (from the lowest keys on a grand piano to just above a middle C) may pass through to the intrauterine environment virtually unattenuated – that is, with little loss in sound energy (Abrams, Gerhardt, & Peters, 1995). On the other hand, high-frequency sounds toward the highest octaves of a grand piano may not clearly emerge from the intrauterine background noise (Querleu et al., 1989).

Several studies have taken recordings from inside the womb in order to assess the clarity of external sounds reaching the intrauterine environment. For instance, Denis Querleu and colleagues (1988) asked French-speaking adults to reproduce the speech sounds they could hear from a recording of voices obtained by a recording device located next to the fetus’ ear. The stimuli used were presented in airborne mode at a conversational level of about 60 dB, and consisted of items from audiometry lists consisting of meaningful and nonsense words (so that participants could not guess inaudible syllables from partially heard words). Querleu and colleagues found that adult participants were able to recognize only around 30 percent of about 3000 phonemes and 22 percent of the consonants. Spoken consonants are higher-pitched than vowels, and thus are subject to greater attenuation than vowel sounds. External speech therefore loses much of its crispness by the time it reaches the fetus.

Similar studies have been conducted using orchestral music. In one study, Woodward and colleagues played Bach’s Brandenburg Concerto No. 1 presented at 80 dB, and recorded the sound from inside the uterus (Woodward, Guidozi, Coley, Anthony, & De Jong, cited in Woodward, 1992). Attenuation of the higher frequencies made the music sound more muffled and less brilliant than the original recording. Despite some loss in tonal quality of higher frequencies, however, many of the distinctive qualities of the music – such as rhythm and orchestra texture – were preserved. In another study, for example, an intrauterine recording of a segment of the first movement of Beethoven’s Fifth Symphony opus 67 was easily identified by adult listeners (cited in Abrams et al., 1998, Figure 4).

**Fetal responses to music**

Fetal responses to music have been investigated in only a handful of studies, but there is some evidence that fetuses respond to music in the last trimester (i.e., last 3 months) before birth. For example, changes in heart rate or motor responses have been reliably observed in fetuses exposed to air-coupled
presentations of Chopin’s *Minute Waltz*, Brahms’ *Waltz No. 15*, Gounod’s waltz from *Faust*, and Bach’s *Organ Prelude BWV 548* (Olds, 1985; Woodward, Guidozzi, Hofmeyer, Kent, & Warton, cited in Woodward, 1992). Kisilevsky and colleagues also found that the presentation of a piano rendition of Brahms’ *Lullaby* evoked heart-rate acceleration at 33 weeks GA and body movements at 35 weeks GA (Kisilevsky, Hains, Jacquet, Granier-Defere, & Lecanuet, 2004).

To date, it is difficult to say whether there is any correspondence between the specific characteristics of music and the type of fetal responses elicited. Shetler (1989) exposed fetuses to ‘stimulative’ and ‘sedative’ music through the air-coupled method. He reported that fetuses responded with faster, more agitated movements to the stimulative music, and softer and more flowing movements to the sedative music. However, it is likely that fetuses simply responded to the broad acoustical differences between these two types of music. Similarly, most researchers have been cautious in drawing any conclusions about fetal preferences for different styles of music. For example, one study showed that heart rate decelerated and frequency of movements was higher in 38-week near-term fetuses listening to a Beethoven piano sonata (*The Tempest*) as opposed to a choral work or rock music (Wilkin, 1995). However, the researcher certainly did not conclude that fetuses have a special preference for Beethoven’s music, but that these responses may be due to the ‘dramatic acoustic changes,’ such as sharp contrasts in volume, tempo, and texture, in the Beethoven piano sonata. Again, it is likely that fetuses are responding to broad acoustical features as opposed to fine characteristics of music.

The possibility that maternal responses might mediate fetal responses should also be considered. Zimmer et al. (1982) played classical and pop music to mothers via headphones placed on the mothers’ ears (not abdomens). The researchers found that 34- to 40-week-old fetuses showed an increase in motor activity and a decrease in respiratory movements when mothers listened to 25 minutes of either classical or pop music, compared to the control condition in which no music was played. These effects were stronger for the genre of music that the mother reported that she preferred. The authors conjectured that the mother’s liking for a piece of music may affect her physiological state (e.g., degree of relaxation and mood), which in turn may affect the fetus’ responses. For instance, if the mother’s abdominal muscles are relaxed when listening to pleasant auditory stimuli, this may increase the amount of space in which the fetus can move (Hepper, 1991). The mother’s role as a possible mediating influence is important to consider in studies in which the mother can hear the music presented to the fetus. After all, the mother usually hears the music to which the fetus is exposed under ‘normal’ circumstances outside the laboratory.
Links between prenatal exposure and newborn responses

Maternal heartbeat and voice

A question that is often asked is whether prenatal exposure to particular sounds can have a lasting influence after birth. For instance, are newborns soothed by the sound of the human heartbeat, as it is a familiar sound from the womb? In a classic study, Salk (1961) found that newborns who heard the sound of a heartbeat of about 72 beats per minute (presented for 4 days) cried less and were more likely to gain weight during those 4 days than were newborns in a control group. However, subsequent studies have yielded mixed results. Many do not suggest a special preference for the human heartbeat, as the same short-term calming effects can be elicited by other rhythmic noises with similar acoustic characteristics. For instance, newborn infants respond similarly to the sounds of the resting heartbeat, lullabies sung in a foreign language, and even metronome clicks at 72 beats per minute (Brackbill, Adams, Crowell, & Gray, 1966). It is possible that fetuses are conditioned to respond to heartbeats through prolonged exposure in the womb, but that this response can be generalized to many other slow rhythmic sounds.

Another question often asked is whether newborns are particularly responsive to the sound of their mothers’ voices. DeCasper and Fifer (1980) showed that infants under 3 days old already prefer their own mother’s voice to the voice of another female. In this study, newborns sucked on a nipple that was connected to sound equipment through a pressure transducer, so that pressure on the nipple could control the audio-track being played. The rhythmic pace of the newborn’s sucking produced either a recording of the mother’s voice or of another woman’s voice. Newborns quickly learned the pattern of sucking that elicited their own mother’s voice and produced her voice more often than that of the other female, even though both women were reading the same prose passage. Originally, DeCasper and Fifer concluded that the newborns had learned to recognize their mothers’ voices after short-term postnatal exposure and only conjectured about the effects of prenatal exposure. However, even newborns under 2 hours old already demonstrate a preference for their own mother’s voice (Querleu et al., 1984) while 2-day-old newborns did not prefer their father’s voice to the voice of another male following 4 to 10 hours of postnatal contact (DeCasper & Prescott, 1984).

Newborns may also respond to familiar passages of prose to which they were repeatedly exposed during the last weeks of their mothers’ pregnancy. In DeCasper and Spence’s (1986) widely-cited study, for instance, expectant mothers were asked to read one of the following stories out loud every day during the last six weeks of pregnancy: Dr. Seuss’ The Cat in the Hat (1957), The King, The Mice, and The Cheese (Gurney & Gurney, 1965), or The Dog in the Fog (a story the researchers created by replacing nouns in The Cat in the Hat). Using the same procedure as in DeCasper and Fifer’s study, the researchers found that 2-day-old newborns preferred the story that had been
read to them while *in utero*, to stories that they had not been exposed to prenatally. Because the familiar story was preferred even if the recording was made by a female that was not the mother, the researchers concluded that newborns can recognize some acoustic characteristics of speech, such as syllabic stress and voice-onset-time of consonants. Indeed, a subsequent study by Kreuger and colleagues suggests that by 34 weeks GA, even fetuses may already respond to familiar verse, as indicated by a cardiac response to a rhyme to which they were previously repeatedly exposed (Krueger, Holditch-Davis, Quint, & DeCasper, 2004).

**Vocal and instrumental music**

Most studies that have investigated transnatal continuity of auditory experience have focused on responses to speech, and relatively few have focused on possible effects of prenatal exposure to music. Using similar methods to the ones devised by DeCasper and colleagues, both Satt (1984) and Panneton (1985) found that newborns preferred a lullaby that mothers had repeatedly sung during the last trimester of pregnancy to an unfamiliar lullaby that the infants had never heard before.

Similar results have been found for voice with accompaniment or instrumental music. Hepper (1991) played the catchy musical theme to *Neighbours* (an Australian television soap opera) to fifteen 2- to 4-day-old newborn infants. When the *Neighbours* theme was played for the first time since birth to newborns whose mothers reported watching the soap opera daily while they were pregnant, the newborns exhibited a decrease in heart rate, a decrease in movements, and tended to adopt an alert state while exposed to the music. Newborn infants whose mothers had not watched the soap opera before did not exhibit any significant changes in heart rate or movements, and very few became quiet and alert upon hearing the music.

The effects of prenatal exposure to music have also been observed both before and after delivery. In Wilkin’s (1995) study, for example, fetuses were exposed to an audiotape of classical and rock music, played daily from 32 weeks gestational age to 6 weeks after birth. Compared to a group of matched controls that were not prenatally exposed to the audiotape, more fetuses in the experimental group showed heart-rate deceleration to presentation of the audiotape at 38 weeks GA. Newborns in this group were also more likely to adopt an alert state when the audiotape was played at 6 weeks after birth.

**Beneficial effects of music for the newborn?**

It is interesting to learn that infants respond differently to some sounds to which they were regularly exposed during the last few months before birth. However, it must be noted that this apparent ‘recognition’ to familiar materials is short term, lasting only a few days to several months after birth.
(e.g., Fifer & Moon, 1989). As yet, there is no hard evidence that prenatal exposure to music or other auditory stimuli ‘teaches’ the fetus something that will carry through to childhood and beyond, nor primes them for exceptional ability. These early ‘memories’ are probably lost in the extensive rewiring of neurons that takes place in the first several years after birth. The main benefits of music listening may be for relaxing the expectant mother, thereby bringing indirect and nonspecific developmental benefits to the fetus.

Similarly, the idea there are lasting benefits of playing classical music to newborns and infants – and in particular, that it can boost cognitive functioning – has not yet been clearly demonstrated in the scientific research. This popular notion, and the way it came to be associated with the Mozart effect (or the alleged enhancement of cognitive skills by listening to classical music, particularly the music of Mozart), has an interesting history. The origin of the so-called ‘Mozart effect’ can be traced back to a brief paper by Frances Rauscher, Gordon Shaw, and Katherine Ky which appeared in Nature in 1993 (followed by a longer 1995 article by the same authors). The study showed that listening to Mozart’s Sonata for Two Pianos in D major (K. 488) for 10 minutes enhanced adult listeners’ performance on standard spatial tasks, compared to listening to a relaxation tape or to nothing at all. Rauscher and colleagues found that those who had listened to the Mozart sonata immediately before completing three spatiotemporal reasoning tests taken from the Stanford-Binet intelligence scale performed significantly better than those in the other conditions. However, the effect was short term, ‘washing out’ after about 10 to 15 minutes.

Rauscher and her colleagues were cautious in interpreting the findings of their study and took pains to point out its limitations. However, when findings of the study were disseminated in the media, where they were dubbed the ‘Mozart effect’ (a phrase which the original researchers never used), the reports often seemed to imply or even directly claim that listening to Mozart can boost intelligence or IQ. The fact that the original study focused on a specific type of intelligence (spatiotemporal reasoning), that the effect lasts only about 10 to 15 minutes, and that subsequent studies have usually failed to replicate the original findings (Chabris, 1999) were often omitted.

Other explanations for the original findings have received far less attention in the media. For instance, the original interpretation of the Mozart effect was that listening to Mozart stimulates neural networks that are also used in spatial reasoning. However, Nantais and Schellenberg (1999) pointed out that the three conditions originally used (Mozart, silence, relaxation tape) did not merely differ with respect to their ability to stimulate this network, but with respect to the boredom they caused in the listeners, which was substantially less for Mozart’s music than the other conditions. Rather than stimulating a specific neural network, subsequent studies suggest that Mozart’s music simply caused more arousal in listeners (Thompson, Schellenberg, & Husain, 2001) and this effect may therefore be brought about by a range of other...
stimuli including music by other composers, music of nonclassical genres, and even recorded prose passages. It has long been known that moderate amounts of arousal can facilitate performance on many tasks.

One of the unexpected outcomes of this research is that – despite the fact that infants were not the focus of the original or subsequent scientific studies from which the idea was derived – the Mozart effect became strongly linked in public perception with the idea of wide-reaching benefits of classical music for infants. Bangerter and Heath (2004) analyzed 478 articles related to the Mozart effect appearing in the top 50 American newspapers starting from the day the original Nature article was published in 1993 until 2002. Their analysis revealed that the percentage of newspaper articles on the Mozart effect that mentioned infants increased from 0 in 1995 to about 55 percent of news reports by 1999. Meanwhile, college students – the participants originally studied – were mentioned in 80 percent of articles related to the Mozart effect in 1994 and this steadily decreased to about 30 percent after 2000! Further, media interest in the Mozart effect seemed to increase only after attention shifted from the actual findings to a focus on the putative benefits of music for infants and children. The Mozart effect may be viewed as a ‘scientific legend’ that drew credibility through association with a scientific study but eventually ‘transformed to deviate in essential ways from the understanding of scientists’ (Bangerter & Heath, 2004, p. 608). A new story line evolved as media reports frequently overextended the findings to untested populations such as newborns, infants, and children.

The impact of the perceived association between the Mozart effect and infants has been widespread. The findings of Rauscher et al.’s studies are often used for ends not intended by the original researchers, such as the sale of CDs, books, and other products claiming that classical music can ‘make babies smarter.’ Classical music CDs citing Rauscher and colleagues’ studies and claiming various benefits for newborns, expectant mothers, and fathers, are widely available. Articles in the news and popular media with titles such as ‘More proof music lifts young IQs’ (Ingram, Toronto Star, May 1997) continue to reinforce the popular belief that scientists have established a link between music and enhanced intelligence in the developing brain. To date, however, there is no body of scientific evidence that has demonstrated a strong or direction connection between exposure to classical music and enhanced cognitive functioning in infants, and many attempts to replicate the Mozart effect in children have yielded no effect (e.g., Črnčec, Wilson, & Prior, 2006, but see Ivanov & Geake, 2003). Only prolonged active engagement in music such as learning to play a musical instrument – not simply listening to music – has been associated with long-term effects on general intelligence (e.g., Schellenberg, 2006, but see Costa-Giomi, 2004).

That is not to say, however, that music may not have other positive effects on young infants. Music has been effectively used in neonatal intensive care units, especially with high-risk infants. Some studies have shown that playing music to low birth-weight newborns may reduce weight loss and stress-related
behaviors, can positively affect oxygen saturation levels and heart rate and respiratory rate, and may reduce the length of hospital stays (e.g., Caine, 1991; Cassidy & Standley, 1995). The Pacifier-Activated-Lullaby method, similar to DeCasper’s paradigm described in this chapter, may help preterm infants to more quickly gain self-sufficiency in feeding (e.g., Standley, 1999). This is important as the sucking reflex is often too weak to sustain self-feeding until the fetus is around 35 weeks GA, so that preterm infants must often be fed intravenously. Although not all studies show significant effects of music on physiological measures, the trends are often in a positive direction. Music therapy can also benefit infants of depressed mothers by altering the mother’s mood and reducing high arousal levels in their infants (Field, 1998). Singing to infants can also play a role in restoring attachment between infants and family members when bonding has been disrupted by lack of early physical contact with newborns restricted to isolettes (O’Gorman, 2007). The therapeutic use of music with newborns is explored in practical guides such as Music Therapy for Premature and Newborn Infants (Nöcker-Ribauerpierre, 2004) and Music Therapy with Premature Infants: Research and Developmental Interventions (Standley, 2003).

Part Two: Music perception and cognition in the infant

William James (1890, p. 488) used the phrase ‘one great blooming buzzing confusion’ to describe the world as it might be experienced by the newborn infant. Like many others in his day, he assumed that infants were poorly equipped to process the rich information flooding their senses. This view has changed dramatically with accumulating evidence of infants’ acute sensory capacities.

The first part of the chapter described how the cochlea is functionally complete at birth. A few auditory structures are not yet fully developed in the newborn; the tympanic membrane (eardrum) is open at birth and closes by about age 3 years, and the ear canal is straight at birth and assumes the adult S-curve by the end of middle childhood (Snow & McGaha, 2003). The lack of maturity of these structures, however, does not seem to interfere significantly with basic auditory capacities. In the second part of this chapter, we focus on music perception and cognition in the infant. By the end of our discussion, we should have greater insight into why psychologists have replaced the old Jamesian view with the idea of the ‘sophisticated infant,’ already handily equipped to process complex sensory stimuli.

Orientation to sound

The newborn already responds actively and curiously to sound, as seen in the tendency to turn toward the source of a sound shortly after birth. Spontaneous head-turns towards the sound of a rattle presented to the left or right side have been observed in 2- to 4-day-old newborns (Muir & Field,
1979). Some 2-day-old newborns even adjust the position of their heads to track a continuous sound that moves to different points within the same hemi-field (i.e., the same side of the head), though with limited accuracy (Morrongiello, Fenwick, Hillier, & Chance, 1994). After 6 months, most infants can turn their heads within 4 to 6 degrees of a sound source (Morrongiello & Rocca, 1987). And by 7 months, infants can even reach for sound-emitting objects in the dark, relying solely on their sense of hearing in the absence of visual cues (Stack, Muir, Sherriff, & Roman, 1989).

Infants’ ability to localize sound does not match adult performance, however. As discussed in chapter 3, our ability to infer where a sound is coming from relies on many cues. Two of the binaural cues are interaural timing (if a sound reaches one ear before the other, the source is judged to be closer to that ear) and interaural intensity (if the sound is louder in one ear than the other, it must be closer to the source). Infants’ poorer performance on sound localization tasks may be due in part to the small size of infants’ heads. Figure 8.1 shows the head circumference of a newborn infant, taken a few

Figure 8.1 First measurement of a newborn’s head at birth (~13.5 inches, taken directly after birth).

Source: Photograph used with permission from the parents of the newborn. Copyright © Peter Pfordresher.
minutes after birth. Though disproportionately large for the body (newborns’ heads are about 1/4 to body mass while the adult ratio is 1/8), the distance between the two ears is much smaller than in adults. Thus, interaural differences in timing and intensity are more difficult to detect. Infants’ heads may also not be large enough to produce the ‘sound shadow’ that conveys cues as to the location of sounds due to sounds having to travel around the head and being absorbed by the head. Further, as young infants spend a lot of time lying on their backs, this too would affect accuracy in detecting sources of sound, as sound localization is more difficult when supine than when standing.

**Perception of pitch**

The fetus is mainly exposed to low frequencies while *in utero* (for reasons discussed earlier in this chapter) but after birth, infants are more attentive to high-pitched sounds. For both infants and adults, hearing is most acute for frequencies in the 2000 to 4000 Hz range, corresponding roughly to C7 to C8, or the highest C octave on a grand piano (Fernald, 2001). Indeed, for sounds above 4000 Hz, 5-month-old infants perform better at some pitch discrimination tasks than adults, although at lower frequencies infants’ hearing is significantly poorer than adults (Olsho, 1984). Thus improvement in
frequency discrimination and other areas of listening does not increase in a broad progression across all frequencies; there is significant progress in hearing ability in high frequencies during infancy but low-frequency discrimination advances more slowly and continues into late childhood.

Infants also demonstrate sensitivity to pitch as they imitate voices and other sounds. In an important early study, William Kessen and colleagues trained 3- to 6-month-old infants to sing pitches D, F, and A above the middle C by playing them repeatedly (Kessen, Levine, & Wendrich, 1979). After about 2 weeks of training in the laboratory and at home, most 3- to 6-month-old infants were able to sing back two or three of the pitches with fairly reliable accuracy. Accuracy of pitch-matching was evaluated by five musicians, who judged about 70 percent of the infants’ vocalizations to be within a quarter-tone of the target pitch. This finding was surprising at the time, because it was previously believed on the basis of psychoanalytic (Freud, 1924) and learning theory (Bandura & Walters, 1963) that infants could not perform matching behavior until nearly 1 year of age.

There is evidence that sensitivity to consonance and dissonance also emerges at a very early age. Even by 2 months, children prefer harmonic intervals (i.e., pitch intervals formed by simultaneous tones) that are consonant to those that are dissonant (Trainor, Tsang, & Cheung, 2002). This finding makes sense given that the consonance of simultaneous tones likely reflects the mechanics of the cochlea (Plomp & Levelt, 1965, as discussed in chapter 3). However, even sensitivity to consonance in melodic intervals – that is, those formed by successive rather than simultaneous tones – emerges early in life, perhaps by 6 months of age (Schellenberg & Trehub, 1996). Other aspects such as pitch perception within a particular scale system, however, may require a little more time and exposure to assimilate. Western adults are much better at detecting tuning changes in melodies written in familiar scales (e.g., major or minor) versus unfamiliar scales (such as Javanese pêlog, discussed in chapter 15). Young Western infants, on the other hand, discern mistuning equally well in melodies in either scale (Lynch, Eilers, Oller, & Urbano, 1990) until about 12 months of age, after which they show greater sensitivity to tuning changes in melodies based on a major scale, as do Western adults (Lynch & Eilers, 1992).

To date there is little neuroscientific research on music perception in infancy, though this area is growing. One line of inquiry concerns how the brain processes simple pitch differences. Although there is evidence that this perceptual ability seems to be present early based on what we know from behavioral data, it is possible that the brain’s response evolves over time. In fact, this does seem to be the case, based on measurements of event-related potentials (ERPs, see chapter 4) in infants. Researchers at McMaster University led by Laurel Trainor have measured EEG responses in infants using a specialized electrode cap (as shown in Figure 8.2) that stays securely on a baby’s head during all the squirming and fussing that often occurs. A series of studies by this group measured ERP responses to pitch in 2- and 4-month-
old infants, and in adults (He, Hotson & Trainor, 2007, 2009). Participants were presented with single tones that would typically be identical, with an occasional ‘oddball’ tone thrown in. At issue was how the brain would respond to the ‘mismatch’ of these oddball tones. It was found that the brains of 4-month-old babies responded very rapidly to oddball tones as do adults. However, the same rapid responses were not found in 2-month-olds – their brains appeared to respond more slowly although they still responded to the mismatch.

**Perception of melody**

Infants do not simply respond to single pitches in isolation; they also follow the general shape of rising and falling tones within a melody. For instance, Hsing-Wu Chang and Sandra Trehub (1977) showed that 5- and 6-month-old infants know that an exact transposition of a melody they have heard before is not a ‘new’ melody. The researchers employed the habituation procedure, commonly used in infant studies. In this procedure, a sound is repeatedly presented to an infant and a physiological measure (in this case, heart rate) is monitored. The baseline heart rate is first taken. Then an auditory stimulus A is repeatedly presented. Infants’ heart rate tends to decrease when first attending to a new stimulus, but returns to a normal baseline rate when the infant gets used to the stimulus after repeated presentation. (In infants, a decrease in heart rate seems to indicate interest or attention, whereas an increase often indicates fear.) After the heart rate returns to baseline readings, a new sound (stimulus B) is repeatedly presented. If the infant’s heart rate decreases, departing again from baseline level, this suggests that the infant recognizes that it is a new or different sound from before. No change in heart rate would suggest that the infant does not discriminate between the two stimuli.

In Chang and Trehub’s study, the same six-note melody was presented repeatedly to infants. Then, either an exact transposition of the original melody (the entire melody shifted up or down by three semitones), or a scrambled melody (the same six tones of the original melody played in a random order) was played. They found that the infants’ heart rate did not decrease when the transposed melody was played. However, heart rate decreased when the scrambled melody was played, indicating that the infants detected that it was different from the original melody. The researchers concluded that just as for adults, transposed melodies sound like the original version to 5- and 6-month-old infants, whereas scrambled melodies are heard as ‘new’ or ‘different.’

A ‘transposed melody’ preserves the melodic contour of the original melody because the exact relationship between each interval is retained, whereas changing the order of the notes for the ‘scrambled melody’ changes the melodic contour. Chang and Trehub concluded that infants do not attend to the specific pitches of a melody (e.g., A, D, F, etc.), nor to the exact intervals
between the pitches, but to the general contour of the melody. This may be why most infants can detect the difference between two six-tone melodies that differ only in one pitch if it changes the melodic contour (Trehub, Thorpe, & Morrongiello, 1985), but often cannot discriminate between two melodies that differ in as many as three or more tones if the melodic contour is preserved (Trehub, Bull, & Thorpe, 1984).

The studies cited above suggest a dominance of relative pitch perception, in that infants treat exact transitions of melodies as if identical to the original melody. At the same time, some evidence suggests that absolute pitch representations may be more prominent than once thought (see chapter 5 for further discussion). Research by Jennifer Saffran and Gregory Griepentrog (2001) led to a surprising conclusion: Infants (8 months old) may learn melodies through absolute pitch rather than through relative pitch. The focus in this paper was on transitional probabilities among pitches, which refers to the likelihood that a particular event (e.g., the note C♯) will follow another event (e.g., the note B). Saffran and Griepentrog tested how well infants could learn these transitional probabilities through exposure. They found evidence for this kind of ‘statistical’ learning, as the infants paid less attention to sequences comprising high transitional probabilities than those for which the transitions were unlikely. The critical twist was that infants could distinguish ‘new’ from ‘old’ sequences even when the new and old sequences included the same pitch intervals. By contrast, infants were not as good at distinguishing new from old when the distinction required learning contingencies across pitch intervals (e.g., learning to identify a given melody in multiple ‘keys’).

How does one reconcile findings such as those of Chang and Trehub (1977) and Saffran and Griepentrog (2001)? One possibility, suggested by the authors of the latter paper, is that most studies focus on infants’ ability to extract global information about a melody, but do not test whether infants can learn local information like absolute pitch. Another possibility, suggested by Plantinga and Trainor (2004), is that the answer lies in the kinds of materials that are used. Saffran and Griepentrog used three-note melodies that were atonal in nature. Although infants may not have internalized Western tonality, they have been shown to be better able to learn asymmetric scale structures (scales in which intervals between pitches are not all equal, like the diatonic scale) than the chromatic scale, which is symmetric and used for atonal music (Trehub, Schellenberg, & Kamenetsky, 1999). Consistent with this view, Plantinga and Trainor (2004) found that infants exhibited no preference for a tonal melody in its original key versus a transposed version of that same melody. Plantinga and Trainor, unlike Saffran and Griepentrog, believe that relative pitch dominates infant memory for melody for truly ‘musical’ sequences. Suffice to say that the study of pitch perception in infancy is a lively one at present.
Perception of rhythm and meter

Just as infants are able to recognize the basic contour of a melody when it is played in another key, they also recognize rhythms when played at different speeds. Sandra Trehub and Leigh Thorpe (1989) found that 7- to 9-month-old infants can differentiate between similar rhythmic patterns (e.g., XX XX versus XXX X, or roughly a five-beat pattern with a silent third or fourth beat) if the tempo (speed) at which they are played is changed, as long as the relative durations between each tone is preserved. When the pitches were changed, infants also differentiate between rhythmic patterns that are similar but not the same. The tendency to focus on relative pitches between tones of a melody and relative durations of tones in rhythms as opposed to absolute pitches and time durations, allows listeners to recognize a song – even if transposed to a different key or played at a different tempo.

Seven-month-old infants also seem to be sensitive to the accent structure of music, as demonstrated in an innovative study by Jessica Phillips-Silver and Laurel Trainor (2005), illustrated in Figure 8.3. In this study, a recording of 2 minutes of a rhythm pattern that had no accented beats was played to 7-month-old infants. As the music played, researchers held the infants in their arms and bounced them either to every second beat, or every third beat, of the rhythm. Therefore, although all infants heard the same unaccented rhythm, the ‘felt’ accents were different. During the test phase, two versions of the same rhythm pattern the infants had heard before were presented – but this time, the rhythm was clearly accented either on every second or every third beat (i.e., duple or triple structure). Infants who had been bounced in duple time preferred the version that was accented on every second beat, as indicated by longer attentive listening time. Infants who were bounced in triple time preferred the version that was accented on every third beat.

Blindfolding the infants while they were being bounced to the ambiguous rhythmic pattern produced the same results. Again, the infants showed a preference for the rhythm presented in the structure to which they had been bounced before. However, when babies merely observed an adult jumping in duple or triple pattern to the ambiguous rhythm while the infant sat still, the infants showed no clear preference for the duple or triple pattern audio track. Thus, visual cues alone do not seem to play an important role in infants’ representation of beat structure. The infant has to feel the beat with the movement of his or her own body, thus incorporating both auditory and vestibular cues in interpreting rhythmic structure. Similar studies carried out by the same researchers have yielded parallel findings in adults, showing that they too ‘hear what the body feels.’ Phillips-Silver and Trainor point to a cross-modal interaction between body movement and auditory interpretation of rhythmic structure that emerges early in infancy and is maintained in adulthood: ‘how we move will influence what we hear’ (2007, p. 535, original emphases).
Sensitivity to particular meters may depend on exposure, as shown in a study by Hannon and Trehub (2005a) that was briefly mentioned in chapter 6. Hannon and Trehub found that when Balkan folk melodies of Serbia and Bulgaria were played to North American adults, they could differentiate between changes in the melody that deviated from the original metrical structure versus those that preserved the meter. However, the adults could only do so for Balkan melodies presented in simple meters (which are prevalent in Western music) and not for those in complex meters (which are rare in Western music). North American infants of 6 months, on the other hand, were able to discriminate between meter-disrupting and meter-preserving deviations from the original Balkan folk melody in both simple and complex meters.

Figure 8.3 Conditions used in Phillips-Silver and Trainor’s (2005) study: (a) Bouncing while watching experimenter. (b) Bouncing while blindfolded. (c) Passively observing experimenter. (d) Preference test.

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Parallel to the finding that infants begin to show greater sensitivity to the tonal systems (e.g., major/minor, pélog) of the music to which they are exposed at about 12 months of age (Lynch et al., 1990), Hannon and Trehub (2005b) also reported that at 12 months old, Western infants were only able to perform the task described above for melodies presented in simple meters (and not the complex meters typical of Balkan music). It is possible that infants start with a flexible style of processing tonal and metrical structure, which takes on a more culture-specific character especially after about a year of maturation and exposure to a particular musical repertoire. The multi-directionality of development (i.e., the simultaneous expression of both gain and loss) is demonstrated here: As infants gain greater specialization and familiarity with a particular musical repertoire, they also lose a certain degree of openness and flexibility in processing sound as music in other ways. This theme of both ‘gain and loss’ playing a role in becoming specialized will resound in the next chapter on musical development and education.

**Memory for music**

Thus far, the studies we have discussed have examined infants’ immediate responses to musical stimuli shortly after they were presented. But do infants retain music after a period of time has passed? Some years ago, one of your authors (ST) met an 8-month-old infant whose parents claimed that he usually stopped crying at the sound of a particular piece of music: a recording of the pop song ‘Y.M.C.A.’ Whenever the recording was played while he was distressed, the infant would cry only intermittently, or cease crying altogether. Although his parents tried to soothe the infant with other music, the infant appeared to have a preference for ‘Y.M.C.A.’ by the Village People. Can 8-month-olds recognize particular songs?

Addressing the question of young infants’ memory for music under much more controlled conditions, Jenny Saffran and colleagues asked parents to play the slow movements of two piano sonatas by Mozart to 7-month-old infants once a day for 14 days (Saffran, Loman, & Robertson, 2000). After daily exposure to the music for 2 weeks, parents were instructed not to play the recordings for 2 weeks. The infants were then brought to the lab for testing.

Each infant was tested individually, using an infant research method called the head turn preferential listening procedure. In this procedure, a music recording is played when the infant turns his or her head to one side, and switches to another piece of music when the infant turns to the other – much like a ‘juke-box’ controlled by the infant’s head movements. The total amount of time that the infant spends listening attentively to each piece of music is measured, and taken as an indicator of the infant’s interest in the music. During the test session, four test items were played to the infants: two 20-second excerpts of the Mozart sonatas to which they had been exposed (‘familiar’ music) and two 20-second excerpts of new excerpts taken from the
same CD recording (the slow movements of two other sonatas by Mozart) for the ‘novel’ music.

The researchers found that the infants listened significantly longer to the ‘novel’ Mozart piano sonatas than to the ‘familiar’ Mozart piano sonatas. In the first part of the chapter, we discussed how newborns are often calmed or soothed by familiar stimuli. However, preferential listening tasks gauge older infants’ attention and interest, which is usually oriented to stimuli that are novel. We can infer that the infants in Saffron et al.’s study recognized the ‘familiar’ music, as they showed significantly less interest to the music that they had been repeatedly exposed to 2 weeks earlier, than to the ‘new’ music. A control group of infants who had never heard any of the Mozart piano sonatas did not show a significant preference for any of the excerpts.

The CD recordings that the researchers gave to the infants’ parents were filled with 10 minutes of Mozart piano sonatas. Thus, the infants seemed to have retained fairly long and complex pieces of music in their memory following a 2-week delay. Further, the infants could not rely on acoustic differences in the music (such as timbre) because the familiar and novel excerpts were all taken from the same CD of Mozart sonatas, all performed on the piano. Subsequent research employing simpler music (folk tunes played on piano or harp as single-line melodies) by Trainor, Wu, and Tsang (2004) and more complex music (piano pieces by Ravel) by Ilari and Polka (2006) have also demonstrated infants’ ability to retain music in long-term memory after a delay. Studies on infant memory for music therefore lend some credence to our ‘Y.M.C.A.’ anecdote!

**Infant-directed speech and singing**

So far, we have seen that infants demonstrate a sensitivity to elements of music such as pitch, melody, tonality, rhythm, and meter, and appear to be able to recognize familiar music after a time delay. In the final section of this chapter, we discuss how these perceptual and musical abilities also have social value for the infant. Our focus is on two auditory stimuli that are often embedded in daily interactions with caregivers: infant-directed speech and singing.

**Infant-directed speech**

Infant-directed (or ID) speech refers to the distinctive style of high-pitched, melodious speech that speakers often use to communicate with infants. It is distinct from adult-directed (AD) speech with respect to prosody, which refers to the ‘musical’ qualities of speech such as the melody, rhythm, tempo, and intonation of spoken language. Formerly referred to as ‘motherese,’ the distinctive features of ID speech include higher overall pitch, wider fluctuations in pitch and loudness, slower tempo, shorter phrases containing fewer syllables, and longer pauses compared to AD speech (Cooper & Aslin, 1990).

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Pitch contour seems to play a critical role in conveying the message in ID speech. In Anne Fernald’s (1989) words, ‘The melody carries the message in speech addressed to infants to a much greater extent than in speech addressed to adults’ (p. 1505). Common patterns in the ‘melody’ of ID speech include rising contours for eliciting infant attention or encouraging the infant to vocalize or respond, gradually falling contours to soothe an infant or end a turn-taking sequence, and bell-shaped contours for maintaining the infant’s interest or conveying approval (e.g., Papoušek, Papoušek, & Symmes, 1991). These pitch contours are used quite similarly in different languages, including tonal languages (in which pitch inflection conveys meaning, such as Mandarin Chinese) and nontonal languages (such as English and German). Indeed, Mandarin Chinese mothers use pitch contour in speech very similarly to German- and English-speaking mothers. Mandarin-speaking mothers sometimes ‘even violate the linguistic tone rules’ of the Mandarin language when engaging in ID speech (M. Papoušek, 1996, p. 97, regarding Papoušek et al. 1991).

Many studies show that infants prefer ID speech to AD speech (e.g., Cooper & Aslin, 1990), as indicated by measures of attention such as length of attentive looking time. In fact, infants show a preference for ID speech even if it is not in their native language. For instance, Werker, Pegg, and McLeod (1994) found that infants preferred ID Cantonese speech to AD Cantonese speech – regardless of whether their own native language was Cantonese or English. The authors noted that this finding is ‘consistent with the notion that ID communication has universal appeal to infants, over and above any specific differences between languages’ (p. 331). One reason for the salience of infant-directed speech is its heightened emotionality, and neuroscientific research has shown that changes in EEG responses correlate with the emotionality of infant-directed speech among 9-month-old infants (Santesso, Schmidt, & Trainor, 2007).

Researchers have observed that ID speech promotes a sort of social synchrony in interactions between caregiver and infant, for example in facilitating joint attention and turn-taking (Adamson & Russell, 1999; Ferrier, 1985). Signals, such as rising contours to initiate dialogue and falling contours to terminate them, may facilitate smooth turn-taking between partners, and thus regulate the timing of events within an interaction. As Custodero (2002) has described it: ‘The musical nature of our coordinated conversations with babies is similar to the musical conversations between jazz musicians. Both types of communication require a shared understanding of the musical structure, like “your turn, my turn”’ (p. 6).

**Infant-directed singing**

While attentive to ID speech, infants show even greater responsiveness to infant-directed singing. When 6-month-old infants are presented with recorded audiovisual presentations of their mothers’ ID speech and ID singing,
they stop moving and fix their gaze longer at the singing performance (Nakata & Trehub, 2004). Like ID speech, ID singing is characterized as having higher pitch, slower tempo, greater dynamic range and expressive timing, and longer pauses between phrases than non-infant-directed singing (Trehub, Hill, & Kamenetsky, 1997). Fathers also adopt this style of singing to their infants, although they do so less frequently and do not raise their vocal pitch in ID singing as much as mothers do (O’Neill, Trainor, & Trehub, 2001). Even siblings under the age of 3 years also sing at a higher pitch and use an animated, ‘smiling’ voice when singing to their infant sisters and brothers (Trehub, Unyk, & Henderson, 1994).

Interestingly, even when caregivers are instructed to do their best to sing as if they were singing to their infants, infants can discriminate between infant-present and infant-absent singing styles, showing a clear preference for infant-present singing. For instance, Trainor (1996) found that 5- to 7-month-olds looked significantly longer at the loudspeaker that played infant-present recordings of a song than the one that played infant-absent renditions. Mothers’ and fathers’ singing in the presence of a real infant is also judged by adults to be higher in pitch, slower in tempo, and more engaging in vocal quality (‘warm voice,’ ‘smiling sound’) than when doing their best to simulate singing to an infant (Trehub et al., 1997). Facial gestures and body movements such as smiling and swaying (that occur naturally in the presence of an infant) may affect the vocal quality of ID singing. Smiling, for instance, alters the shape of the vocal tract and the acoustic quality of the singing voice to a warmer tone (Sundberg, 1982).

Lullabies and play songs seem to elicit different responses in infants (Rock, Trainor, & Addison, 1999). Six- and 7-month-old infants were presented with recordings of their mothers singing two versions of a song, once in the style of a lullaby and once as a play song. Infants tended to focus on themselves (looking at their own bodies or objects they were touching such as a toy) to songs sung in the style of a lullaby, but directed their attention outwardly by focusing more at the caregiver when listening to the same song in a play style. Further, as lullabies and play songs have inherently different musical characteristics (such as differences in pitch range and metrical structure [see Trehub & Schellenberg, 1995]), it is likely that the differences in infants’ responses may be more pronounced when singing a song structure that is congruent with the singing style.

The effects of ID singing on sustaining attention, modulating arousal, and coordinating actions of the infant may make singing a useful tool in therapeutic contexts, for instance with infants of depressed mothers and with preterm infants. Depressed mothers often have flat affect in facial and vocal posture – characteristics which do not attract infants’ attention for positive mutual engagement. Depressed mothers also often have difficulty recognizing and attending to the emotions of their infants, leading to rather disjointed interactions. De L’Etoile (2006) proposes that ID singing can be combined with other effective approaches such as Field’s (1998) ‘interactive coaching’
by using ID singing as a tool to help depressed mothers attract and sustain the attention of infants, and train mothers to be more emotionally ‘in tune’ by imitating the responses of the infants while jointly involved in a singing episode. ID singing has also been shown to have physiological effects such as modulation of arousal in infants in the direction of balanced arousal, indicated by changes in salivary cortisol levels after exposure to only 10 minutes of singing (Shenfield, Trehub & Nakata, 2003). Findings such as these have strong implications for therapy with preterm infants, who are frequently under- or over-aroused.

In daily interactions with infants in nonclinical settings, singing is also put to practical use by many parents who sing to infants in the home. ID singing heightens infant attention and reduces body movements (Nakata & Trehub, 2004), facilitating daily routines such as feeding and changing. Singing regulates infants’ emotions or arousal levels (Shenfield, Trehub, & Nakata, 2003) which may be helpful in eliciting attention, inviting interaction and play, soothing and reducing crying, and inducing sleep. Like ID speech, ID singing may play an important role in developing caregiver–infant attachment, for example by maintaining infant attention for sustained interaction, promoting emotional synchrony between caregiver and child, and eliciting positive affect in the infant, which in turn can elicit further engagement by the caregiver (Dissanayake, 2000). Singing can contribute to harmony and cohesiveness in the home as it is incorporated into daily routines such as mealtimes, bedtimes, and chores, and to maintain and create new family traditions (Custodero, 2006). In all these ways, infant-directed singing may have adaptive value for both infants and their caregivers.

Coda

This chapter focused on the audition and perception of sound and music, before and after birth. Far from the Jamesian notion of the newborn’s experience of the world as ‘one great blooming buzzing confusion,’ we see an emerging portrait of a competent infant – whose auditory functioning begins a few months before birth. In their first year, they already demonstrate sensitivity to the basic elements of music such as pitch, melody, tonality, rhythm, and meter. Moreover, infants do not only perceive and respond to music; they also create it. In the next chapter, we examine infants’ and young children’s engagement in musical behaviors – singing, moving to music, and playing with musical toys and instruments – and examine examples of musical inventions and creations of their own making.