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Introduction

Prenatal musical development involves the acquisition of perceptual, cognitive, motor and emotional abilities and information that may influence later musical development. I argue in this chapter that research in this area can shed light on the origins of musical behaviors, not only in human prehistory (phylogenesis) but also within the lifespan of an individual (ontogenesis).

Ontogenetically, the infant is surprisingly sensitive to patterns of sound and movement that adults perceive as musical (Trehub, this volume). The origin and evolutionary function (if any) of this sensitivity is unclear. One possibility is that musical patterns are similar to perceptual patterns to which the fetus is regularly exposed before birth: the fundamental frequency trajectory of the mother's voice, its relationship to breathing, and the rhythm of her heartbeat and footsteps (Parncutt, 1989, 1993).

In spite of a recent renaissance of research on the phylogeny (origins) of music (summarized by Mithen, 2005), no theory currently enjoys broad acceptance. One possibility involves classical conditioning of the fetus during the third trimester by passive exposure to sounds, movements and hormonal changes within the mother's body (Parncutt, in press). Since (changes in) maternal emotional states regularly trigger both (changes in) the patterns of sound and movement to which the fetus is exposed and (changes in) blood hormone levels, the fetus may associate these with each other, giving emotional connotations to patterns of sound and movement.

The importance of the prenatal phase for general psychological development was emphasized by Smotherman and Robinson (1990) and by Hopkins and Johnson (2005). The fetus responds actively to changes in its intrauterine environment in ways that influence its later behavioural and biological development. The prenatal phase may be regarded as a *developmental niche* (cf. Super & Harkness, 1986) with its own unique characteristics but also lying on the same developmental continuum as postnatal niches. Although no-one would question that sensation, emotion, cognition and motor abilities have prenatal origins (Hall & Oppenheim, 1987), most empirical research about these abilities in the late 20th Century ignored the prenatal period, while at the same time repeatedly asking nature-nurture questions that can only be answered by studying the prenatal epigenesis¹ of behaviour.

It is problematic to use the term "music" in conjunction with fetal development. Neither the fetus nor the infant discriminates between music (including singing) and speech; *motherese*² (Papousek, 1996), the playful vocal-gestural interaction between infants and carers, is a mixture of both. Because motherese is not music but may represent music's origin, the term *protomusic* is appropriate (cf. Fitch, 2006) – by analogy to *protolanguage*, the common ancestor of a group of related languages. For similar reasons, it is misleading to speak of "womb music"³ or of "playing music to cows" (Uetake et al., 1997), since the sound patterns presented in such studies are not perceived as music (i.e. not as culturally situated) by the experimental participants. Those

patterns may nonetheless have musically interesting physiological, behavioural or cognitive affects.

This chapter focuses on musically relevant psychological aspects of prenatal development: the development of perception, cognition and emotion, the relationships between them, and the musical and musicological implications of those relationships. The chapter begins by surveying relevant fetal sensory abilities: hearing, the vestibular sense of balance and acceleration, and the proprioceptive sense of body orientation and movement. All those senses are relevant for musical development, since in all known cultures, since music is inseparable from bodily movement and gesture, whether real (Blacking, 1995) or implied (Tolbert, 2001). The chapter goes on to consider what sounds and other stimuli are available to the fetus: what patterns are the earliest to be perceptually learned? It then considers psychological and philosophical issues of fetal attention, “consciousness”, learning and memory. The chapter closes with speculations about the possible role of prenatal development in the phylogenesis of musical behaviours.

The ontogenesis of music

Fetal auditory, vestibular and proprioceptive abilities

All human sensory systems begin to function before birth (Hepper, 1992). The acoustical stimulation to which the fetus is exposed is more diverse and carries more information relative to corresponding discriminatory abilities than visual, tactile, olfactory or gustatory (biochemical) stimulation. In that sense, hearing may be regarded as the dominant sensory modality in the prenatal phase, and infancy as a transition from auditory to visual dominance.

The fetus can hear throughout the second half of gestation. Because the fetal inner ear is filled with fluid, much of the sound heard by the fetus is transmitted to the inner ear through the skull by bone conduction (Gerhardt et al., 1996; Sohmer et al., 2001). The cochlea begins to process sounds at about around 20 weeks gestation; the cochlea reaches adult size at 25 weeks, but continues to develop until birth (Bibas et al., 2007). Motor responses to sound begin during the same period (Joseph, 2000). At 20 weeks, the fetus is sensitive to a narrow band of spectral frequencies around 300 Hz (Hepper & Shahidullah, 1994). As the fetus develops, its auditory abilities - including the perceptible range of spectral frequencies, the discrimination of frequencies and rapid sequences of events, and the storage and recognition of pitch-time patterns - gradually improve and may approach adult levels at birth (Joseph, 2000), even though brain myelination is not complete until several years later.

It is physically impossible for the fetus to localize sound sources (Parncutt, 2006). First, the fetal head does not cast an acoustic shadow at the relatively low frequencies that are transmitted into the amniotic fluid. Second, interaural time differences are smaller for the fetus than for an adult due to the smaller head size and the faster speed of sound in liquid. The fetus therefore has no access to information about the direction from which sounds emanate. Prenatal sound is monophonic and omnidirectional.

The vestibular system (or organ of balance) begins to function at about the same time as the cochlea. The cochlea and vestibular system lie at opposite ends of the (bony/osseous) labyrinth in the temporal bone or inner ear. The vestibular system consists of three semicircular canals that are sensitive to angular accelerations (rotation), and the saccule and utricle which each contain

otoliths (dense structures) that are sensitive to gravity and linear accelerations (horizontal movement in the utricle, vertical in the saccule). The membranous labyrinth grows quickly and attains adult size by the middle of the gestation period; the otic capsule ossifies between 18 and 24 weeks (Nemzek et al., 2000).

Fetal motility and proprioception

An overview of fetal motor development was given by de Vries and Hopkins (2005). Fetal motility begins at about eight weeks' gestation, when the fetus begins to move through the amniotic fluid and to extend and flex its limbs. From then on, the movement repertoire of the fetus gradually expands. Some movements may be regarded as adaptations to the prenatal environment, while others prepare the fetus for postnatal life. In the third trimester, different sleep-wake states are associated with different movement repertoires and different sizes and frequencies of movement. Movements are not confined to the limbs, but also include startles, breathing movements, jaw openings, sucking, swallowing, facial, tongue and laryngeal movements.

As movements develop, so too does *motor control*. Motor control generally involves an interaction between the neural signals that control muscle activity and sensory feedback about the limb location and muscle tension. The spinal reflex arc begins to function during the first trimester, enabling motor signals to bypass the brain, speeding up motor reflexes.

Development of motor control occurs in parallel with development of *proprioception* - the sense of the relative position and motion of parts of the body. Since musical meaning involves the perception of gesture (Tolbert, 2001), which in turn depends on proprioception, the prenatal development of proprioception may be relevant for the later emergence of musical abilities.

Gestures also play an important role in motherese (Trevarthen, 1985). As they get older, infants increasingly understand the meaning of the physical and vocal gestures of their carers and learn to imitate them. It would be surprising if this striking postnatal development did not depend in some way on prenatal exposure to patterns of sound, movement and emotion.

The fetal auditory environment

The fetal auditory environment is rich and varied, and provides many opportunities for prenatal perceptual learning. The fetus is exposed to sounds from both inside and outside the mother's body. Internal sounds include her voice, breathing, heartbeat, digestion, body movements and footsteps (Lecanuet, 1996). Of these, the voice is most often audible (Fifer & Moon, 1994). The internal sounds tend to be louder than the external sounds: Richards et al. (1992) found the mother's voice to be about 8 dB louder to the fetus than the voices of her conversational partners. The fetus is also exposed to patterns of movement that are coupled to sound patterns, such as when the mother walks.

Both internal and external sounds are muffled (low-pass filtered) as they pass through the mother's body and amniotic fluid. Spectral components in the approximate range 100-1000 Hz are attenuated relatively little and may even be slightly amplified, even if their original is external (Richards et al., 1992). When the fetus is exposed to speech, either internally from the mother or from an external source, muffling makes vowels more salient (audible) than consonants and the fundamental frequency contour more salient than spectral information (timbre, phonemes) (cf.

Smith et al., 2003) - consistent with the important role of pitch contour in music perception (Dowling & Fujitani, 1971).

Fetal “consciousness”

The fetus is not conscious in the everyday sense of *reflective* consciousness, that is, the ability to reflect upon perceptual experience. But the fetus has a range of abilities that may be considered part of a broad definition of consciousness, including perception, cognition, and emotion; wake/sleep cycles (Nijhuis et al., 1982); preferences; and attention. Newborns are capable of demonstrating preferences by the rate of sucking on a pacifier (DeCasper & Fifer, 1980), suggesting that the fetus could also demonstrate preferences if a suitable empirical method could be developed. Kisilevsky et al. (2004) investigated the heartrate and movement of fetuses in response to a musical stimulus and observed a change at about 33 weeks, suggesting an ontogenesis of attention.

According to the *levels of consciousness* approach (Zelazo, 2003), adult reflective consciousness comprises separable components that are acquired at specific ages. The ability to label objects (including people) is acquired at the age of about one year, to distinguish self and from others at two, to reflect about ideas or theories and apply rules at three, and to reflect about self and others at four. Since neither the newborn nor the fetus has any of these abilities, we may assert that the fetus is not conscious in the everyday sense. Attempts to ascribe consciousness to the fetus may be regarded as projections of adult reflective consciousness (*animistic projection, anthropomorphism*; Parncutt, 2006).

Prenatal learning

Learning may be defined as acquisition of information that affects later behaviour. Fetal learning has been repeatedly demonstrated by the empirical paradigms of *habituation* and *classical conditioning*.

In habituation, an organism is exposed several times to the same stimulus and gradually stops reacting to it; in everyday language we would say the organism gets used to the stimulus or the stimulus becomes uninteresting for the organism. Leader et al. (1982) observed fetal habituation to a repeated vibrotactile stimulus at 22-30 weeks gestation. In a different habituation paradigm, Shahidullah and Hepper (1994) found that the fetus can discriminate between sounds at 35 weeks better than at 27 weeks.

Other empirical studies have demonstrated that the fetus is capable of associating stimuli with each other by classical conditioning. In that paradigm, stimuli are paired with each other in a temporal sequence, and after several such pairings the organism begins to expect the second stimulus as soon as the first is presented.

Classical conditioning may be regarded as the basic mechanism underlying *statistical learning*. All higher organisms are sensitive to statistical properties of their environment: given many occurrences of event A in different contexts, they learn the probability that it will be accompanied by (or *co-occur with*) event B, that is, the probability that event A predicts event B (*conditional probability*: Fiser & Aslin, 2002). Saffran et al. (1996) demonstrated that 8-month-old infants can learn statistical properties of nonsense speech during only two minutes' exposure. Since statistical learning is such a fundamental means of picking up information about the

environment for all organisms, we may safely assume that humans begin to learn statistically before birth.

Transnatal memory

Transnatal memory is postnatal retention of prenatally acquired information. If the above arguments concerning fetal (lack of) consciousness are correct, transnatal memory is always *implicit*, that is, not under any form of conscious control - unlike an adult's memory for a telephone number, which normally requires conscious effort.

Transnatal memory for stimulus patterns presented repeatedly to different fetal sensory modalities can last for weeks or months and may therefore be considered to be a form of long-term memory (Hepper, 1991, 1992; Hopkins & Johnson, 2005; Mastropieri & Turkewitz, 2001). In experiments to measure the duration of transnatal memory, a given stimulus pattern is presented repeatedly before birth (e.g. a specific piece of music), or a pattern to which the fetus is naturally exposed (e.g. the mother's voice) is used as an experimental stimulus. When the same pattern is presented for the first time after birth, or in a specific new way, the reaction of the infant is observed and compared with its reaction to unfamiliar control stimuli.

Episodic memory involves memory for a specific event. The existence of *transnatal episodic memory* is suggested by reports of therapeutic patients in trance states who seem able to recall prenatal events or the experience of their own birth. Hartogh (2003) questioned the validity of such evidence. In general, memories are affected by relevant knowledge and by cultural and social context, and can easily be constructed (Harris et al., 1989). Since episodic memory in humans normally depends on language, and since prenatal episodic memory has no known evolutionary function, prenatal episodic memory is unlikely to exist. But that does not necessarily prevent prenatal regression therapy from having a useful therapeutic function.

The phylogenesis of musical behaviour

Recent research about the origins of music (summarized by Mithen, 2005) has considered many scenarios. One involves prenatal exposure to the internal sounds and movements of the mother's body, which are associated with her changing physical and emotional state (Parncutt, in press). The claim is that the associations between sound, movement and emotion upon which music is based are ultimately of prenatal origin.

Emotion

Strong emotions are generally associated with reflexes, instincts or drives that promote survival and reproduction (Tinbergen, 1989), such as hunger, sex, fear, pain, disgust, jealousy, surprise and anger. Music is exceptional in that it communicates strong emotions that are marked by changed states of consciousness and spiritual experiences (Gabrielsson & Lindström Wik, 2003), although it has no clear survival value. A plausible theory of the origins of music should be consistent with this fundamental contradiction.

It is often supposed that music is emotional because it is associated with social behaviour and group survival (e.g., Dean & Bailes, 2006). However, evolutionary theory primarily explains the behaviour of isolated pairs of individuals (e.g. reciprocal altruism) rather than groups considered

as a whole (Boyd & Richerson, 1988; Trivers, 1971), and such an approach cannot easily explain music's *strong* emotionality and spirituality.

Musical emotions are associated with learned patterns of sound and movement. A possible source of those associations is motherese (Dissanayake, 2000), whose vocabulary of gestural meanings evidently includes a universal component (Kuhl et al., 1997; Papousek, 1996). The question arises as to the origin of those gestural meanings.

Infant musical skills: Innate or learned?

Another surprising thing about music is that all humans, including infants, possess basic musical skills. A plausible theory of the origins of music should be consistent with the documented musical abilities of infants. Trehub and Hannon (2006) proposed that "infants' music perception skills are a product of general perceptual mechanisms that are neither music- nor species-specific. Along with general-purpose mechanisms for the perceptual foundations of music, we suggest unique motivational mechanisms that can account for the perpetuation of musical behavior in all human societies" (abstract). Prenatal associations between patterns of sound, movement and emotion could underlie such "general perceptual mechanisms" and "unique motivational mechanisms". If so, they may explain the nature and origin of musical emotion.

Several sources of evidence suggest that the musical abilities of infants are at least partially inborn. Amusia can be inborn or genetically determined in a small proportion of the population (Ayotte et al., 2002). Children of deaf parents prefer infant-directed singing over adult-directed singing, suggesting an innate component - or at least an inborn preference for exaggeration (Masataka, 1999). The development of musical ability is affected by prenatal testosterone levels (Sluming & Manning, 2000).

But models of the interplay between genes and environments (Garcia Coll et al., 2004) suggest that behaviors and skills such as musicality are neither inborn nor innate, but a mixture of the two. Several empirical studies cited in this chapter are consistent with the prenatal learning of protomusical skills. For example, newborns respond to the emotional content of speech, but only in their maternal language, suggesting that their ability to recognize that emotion was acquired before birth (Mastropieri and Turkewitz, 2001). The claim that musical skills are *largely* learned may be valid throughout the lifespan. In early life, the gestural vocabulary of motherese may be largely learned from prenatal exposure to the internal sounds of the mother's body. Later, musical expertise may depend primarily on the total accumulated duration of practice (Howe et al., 1998).

Fetal-maternal communication

Bonding (secure attachment) between primary caregiver and infant plays an important psychological and physiological role in early development (Schore, 2001). The idea that maternal-infant bonding is an evolutionary adaptation is consistent with high rates of infant mortality among both non-human primate and human hunter-gatherer populations (>50%: Denham, 1974). Maternal-infant bonding generally increases the chance of infant survival, but not necessarily of surviving infanticide or of preventing abandonment when chances of survival are particularly low (Hausfater, 1984). Prenatally acquired knowledge about maternal emotional states may promote postnatal bonding and survival by helping the infant to communicate its needs appropriately (cf. Broad et al., 2006) and may in that sense be adaptive. Other factors being

equal, the chance that an infant will survive to reproductive age will increase if infant demands on the mother or other carers do not radically exceed their momentary capabilities or resources.

Infant-bonding is two-way and reciprocal (Lee, 2006): each party is at some level sensitive to the physical and emotional state of the other. Empirical research is beginning to document the infant's active perception of the mother: compare Stern's (2002) cognitive, psychoanalytic approach with Trevarthen's (1980) concept of intersubjective communication. To successfully monitor the mother's physical and emotional state, the infant must have prior knowledge about the relationship between maternal state and behavior. The fetus has constant access to two reliable sources of information about the physical and emotional state of its mother: *behavioural* (sound and movement) and *biochemical* (blood hormone concentrations).

Regarding behavioural information, all patterns of sound and movement that are audible within the body in everyday situations, including vocalization, respiration, circulation, movement, footsteps and digestion, depend on physical and emotional state (Mastropieri and Turkewitz, 2001). The human fetus has access to three behavioural sources of information about maternal state: sound patterns, linear and rotational acceleration of the fetal body, and relative movement of the fetal limbs. These are perceived by the fetal auditory, vestibular and proprioceptive systems respectively.

Regarding biochemical information, the hormones involved in the maternal-fetal interaction arise from three different sources: the placenta, maternal organs and fetal organs (Power & Schulkin, 2005). The placenta and fetal membranes produce a large number of steroids that regulate and balance both maternal and fetal physiology. They include progesterone and estrogen, which play a role in maintenance of pregnancy and support of the embryo/fetus (Albrecht et al., 2000); testosterone, which affects fetal development (Matt & MacDonald, 1984); estrogen, related to female secondary sex characteristics (Nelson & Bulun, 2001); corticotropin-releasing hormone, which influences the duration of pregnancy (Hillhouse & Grammatopoulos, 2002); relaxin, which facilitates birth (Klonisch et al., 1999); and placental lactogen (somatomammotropin), which influences nutrient (carbohydrate, lipid) levels in the maternal blood (Walker et al., 1991). In an evolutionary approach, hormonal manipulation of maternal nutrient supply represents an early stage of parent-offspring conflict (Wells, 2003).

Hormone production in the mother involves a mixture of regular adult hormonal processes and processes specific to pregnancy. Regarding the former, externally caused stressors (flight-fight reaction) lead to stimulation of the adrenal gland, which secretes adrenaline (epinephrine) and noradrenaline (norepinephrine) into the blood, which in turn increases blood sugar, muscle tension, and blood pressure. Stress also causes the release of corticotropin releasing hormone (CRH) and the production of glucocorticoids that affect immune responses (Elenkov et al., 1999). CRH is also associated with anxiety and depression (Steckler & Holsboer, 1999), and cortisol is associated with fear and stress (Kalin et al., 1998). Oxytocin is more specific to reproduction and is associated with orgasm, birth and breastfeeding (Newton, 1978).

That the fetus is sensitive to hormone concentrations in the maternal blood is clear from studies that demonstrate the effect of those concentrations during pregnancy on postnatal development. For example, postpartum concentrations of testosterone, estradiol, androstenedione and cortisol correlate with the children's later levels of physical aggression (Susman et al., 2001). Molecules that pass the blood-brain barrier include oxygen, carbon dioxide, alcohol, and steroid hormones, of which there are five main groups: progestagens, glucocorticoids, mineralocorticoids,

androgens, and estrogens (Pardridge & Mietus, 1979). The permeability of the blood-brain barrier to steroid hormones depends on the molecule and involves different temporal delays (Zloković et al., 1988). The placenta is permeable to nutrients, oxygen, alcohol, antibodies and steroid hormones with different temporal delays of seconds, minutes or hours (Bajoria et al., 1998; Bajoria & Fisk, 1998).

Thus, both evolutionary-biological and developmental-psychological approaches predict that the fetus perceives changes in patterns of sound and movement within the mother's body (behavioral information) following everyday changes in maternal state. The corresponding changes in maternal hormone levels are delayed by passage through the placental and fetal blood-brain barriers (biochemical information). The behavioral change thus predicts the biochemical change, allowing classical conditioning to occur – just as, in Pavlov's famous experiment, the footsteps of a master bringing food to a dog predict the appearance of the food.

Any stimulus can be associated with any other by classical conditioning, and all animals are capable of classical conditioning. The human fetus is no exception (Smotherman & Robinson, 1990). The fetus must therefore learn to associate the behavioral information described above with the corresponding biochemical information. The theory of classical conditioning predicts that after several repetitions of such a sequence the fetus will begin to respond emotionally to the behavioral patterns - before the arrival of the biochemical information. While the time interval between behavioural and biochemical information in this scenario is presumably of the order of minutes, classical conditioning may also occur for longer interstimulus intervals of the order of hours (Garcia et al., 1974).

Prenatal influences on postnatal behaviour

Prenatally established associations can influence postnatal behaviours and the development of musical culture in the context of *motherese*, *play* and *ritual*. In all three cases, *operant conditioning* (Skinner, 1938) may be the underlying mechanism. Patterns of sound and movement that occur by accident in these behaviours may be similar to patterns of sound and movement that were prenatally linked to emotion. The triggering of associated emotions may reinforce the actions or behaviours that produced the patterns of sound, increasing their frequency of occurrence. Since motherese, play and ritual are social activities whose participants were subject to similar prenatal conditioning processes, this theory predicts that such behaviours and associated emotions will generally be socially shared, enabling the development of music as a form of social behaviour.

On this basis, we might expect to find associations between sound, movement and emotion in all prenatally hearing animals. The reason why non-human animals are not musical in the human sense is presumably that only humans possess reflective consciousness, which emerged at least 60,000 years ago and enabled a *cultural explosion* (Mithen, 2005). Reflective consciousness may be regarded as a co-requisite for the ability to conceptualise the past and future in relation to the present, which enables deliberate/intentional planning and action (Noble & Davidson, 1996). According to this view, prenatal associations between sound, movement and emotion became "music" when humans acquired the ability to deliberately manipulate socially shared emotions – that is, to perform.

Conclusions

Recent research in music psychology has tended to avoid questions of prenatal development due to the practical and ethical difficulties associated with empirical investigations and the dubious quality of much of the available research literature. This period of restraint may be coming to an end as researchers realise that the prenatal period could be a source of answers to central questions in music psychology, and as developing empirical technologies make it increasingly possible to carry out methodologically sound empirical investigations.

The relevant empirical literature is expanding rapidly, but it is spread over many different disciplines, and many central issues remain to be critically addressed by independent research groups. The present theory presented on the origins of music may be internally consistent and logical, but further empirical work will be necessary to investigate the details of the hypothesized prenatal associations and their effect on postnatal behaviour.

Since our knowledge of music's emergence in the context of ritual will always be limited, any theory of music's phylogeny will always be speculative. The ontological question of how prenatal learning affects postnatal musical development will become increasingly accessible to empirical investigation, as non-invasive observational techniques improve. An improved understanding of the interaction between genes and environment in psychological development (e.g. Bakshi & Kalin, 2000), combined with new approaches to fetal behaviour (such as preferences) and prenatal influences on postnatal behaviour (including transnatal memory), will lead to new insights that will confirm, complement, challenge or overthrow the ideas presented in this chapter.

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¹ The word “epigenesis” (rather than genesis) refers to the role of both nature (genetics) and nurture (environment), and the interaction between them, in the prenatal emergence of behaviour.

² I use the term *motherese* rather than *infant-directed speech* to emphasize the two-way nature of this form of communication (including the active role of the infant) and the musically central role of women (especially in discussions of the phylogeny of music). Of course men (not only fathers) and women other than mothers can and should also speak motherese.

³ E.g. “Babies remember womb music”, <http://news.bbc.co.uk/2/hi/health/1432495.stm>, viewed on 11 August 2007