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Chuckrow's theory of the prenatal origin of music

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Abstract

In 1965, the second author, a graduate student in physics at New York University, drafted a paper entitled "Music: A synthesis of prenatal stimuli," in which he proposed that structural elements of music such as rhythm and melody are analogs of fetal stimuli. In the 1980s, the first author independently published a similar theory. Both authors considered fetal perception of internal body sounds, correlations between those sounds and maternal states, the ability of the fetus to hear and remember sound patterns, biological and behavioral correlates of emotions shared by mother and fetus, transfer of hormones across the placenta, and effects of maternal psychopathology on infant behavior. Both argued that consideration of fetal consciousness is unnecessary because unconscious learning can influence later conscious behaviors and experiences. Chuckrow uniquely proposed that meter and polymeter, perceived as combinations of approximately isochronous pulses with one pulse in the foreground, might derive from the combined sound of maternal and fetal heartbeats as perceived by the fetus. We evaluate these theories in the context of more recent approaches to the origin of music. A systematic consideration of prenatal influences can parsimoniously explain communicative, emotional and structural aspects of music. Music may be a by-product of adaptations such as prenatal hearing and motherese that promoted infant survival in ancient hunter-gatherer settings.

Keywords

Prenatal, origin, music, voice, heartbeat, footsteps, melody, rhythm, harmony, emotion

Introduction

Language is clearly adaptive, but music may be no more than an evolutionary exaptation—a by-product of adaptations such as language, motor control, vocal emotional communication and auditory scene analysis (Pinker, 1997). If evolutionary theory explains aspects of the arts, including literature and painting, it may be because they are by-products of other adaptive abilities and proclivities of ancient humans (Dutton, 2009).

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Musical emotions and musical origins are interconnected (e.g. Scherer, 1995). Music evokes a wide range of social-emotional responses, but some occur more often in music than in everyday life. Transcendent musical emotions (Becker, 2004; Zentner, Grandjean, & Scherer, 2008) may thus provide clues to music's specific origin.

A previously unpublished theory of the origin of music by the second author (Chuckrow, 1965) is reproduced in the Supplementary Online Material of this journal. It is surprisingly similar in approach and details to research published later and independently by the first author (Parncutt, 1989, 1993, 2009a, 2009b, 2016). Our aim in this contribution is to present and compare these two sources, while also considering Chuckrow's claims in the light of relevant recent empirical literature (e.g. Ullal-Gupta, der Nederlanden, Lahav, & Hannon, 2013). On this basis, we will offer a revised speculative framework within which both musical emotion and music's origin may be understood. Given the proliferation of theories of music's origin and the continuing absence of a widely accepted theory, an approach based on prenatal perception, cognition and emotion has become a promising alternative for detailed investigation.

Current approaches to the origin of music

The psychological literature on the origin of music is complex. In this section we briefly introduce and evaluate selected leading approaches. It is within this empirical and theoretical context that our approach can be evaluated.

Protomusic versus music

Many non-human species, including whales, gorillas, seals and songbirds, exhibit behaviors similar to human singing, and certain behaviors of chimpanzees, bonobos and gorillas are similar to human drumming. Motherese, a playful game of sound and gesture shared by mothers and infants in all cultures, is also protomusic (Hillert, 2014). It is unclear whether there is a causal evolutionary connection between such behaviors and human music and, if so, how such connections can be analyzed (Fitch, 2006).

Behavioral prerequisites versus motivations

Non-human species and infants that exhibit protomusical behaviors evidently possess both the necessary physiological prerequisites (the *music faculty*) and the motivation to behave in those ways. It is relatively clear how physiological prerequisites for human music such as auditory sensitivity, vocal-tract flexibility and a larger brain developed (Morley, 2002). We know less about motivations for protomusical behaviors. Early humans with physiological prerequisites for music did not necessarily use them to make music (as exaptations), nor did the physiological phenomena necessarily evolve for the purpose of making music (as adaptations). If "a vocal apparatus similar to the modern was present in *Homo heidelbergensis* 400,000–300,000 years ago" (Morley, 2002, p. 195) because it promoted effective communication (speech), it was not necessarily used for singing.

Neurophysiology versus ecology

The partial separation of music and language areas in the brain (Peretz & Coltheart, 2003) suggests that music's emergence involved neurophysiological changes. However, every form of behavior has neurophysiological correlates, so those changes may not have been causal. Music's emergence may instead have been driven by changes in the human situation—interactions with the physical, biological or social environment (Withagen & van Wermeskerken, 2010).

Separation of music and language

In their complex, self-reflective human manifestations, music and language may have emerged from a single phenomenon called *musilanguage* (Brown, 2000). Music and language separated because they had different social functions, language being more lexical (or propositional—suited to everyday tasks and problems) and music was more prosodic (for ritual situations that promote social cohesion).

Cultural explosion

The separation of music from language may have preceded and enabled the "cultural explosion" some 100,000 years ago (Mithen, 2005). Depictions such as cave paintings and body decorations, and the use of art in spiritual/religious rituals, may have driven the transition from simple symbolic acoustic communication to complex reflective language (Davidson & Noble, 1989). Music and religion may have emerged in parallel with the emergence of reflective language and consciousness (d'Errico et al., 2003).

Origin of music-specific emotions

Music evokes "transcendent" emotions such as wonder, sublimity, magic, enchantment, sacredness, spirituality, awe, reverence, glory, majesty, splendor and mystery (cf. Becker, 2004; Zentner et al., 2008). The higher frequency of such emotions in music by comparison to everyday life is evidence for a fundamental link between music and religion, which might explain the co-occurrence of music and religion in all known human societies (exception: politically motivated musical suppression; Korpe, Reitov, & Cloonan, 2006). Theories of music's origin based on partner selection and social coherence cannot directly explain transcendental musical emotions.

Transfer between musical and non-musical skills

Music-making can improve non-musical skills of many kinds—cognitive, perceptual, motoric, emotional and social (Hallam, 2010). Music may therefore have evolved because children who engaged more often in (proto-) musical activities developed better survival skills than other children and therefore survived with higher probability (Roederer, 1984). In this scenario, different skill-promoting features of song and dance may have emerged separately and later combined into "music" (a linguistic construct of "high cultures"; Gourlay, 1984). If we consider cost/benefit ratios (Trivers, 1971), the benefits of music-making (such as social cohesion or skill acquisition) must be greater than the costs (the time and effort put into this activity) if evolutionary theory is to explain the emergence of such complex behaviors. But the amount of time and effort put into music, at least by modern musicians, is enormous (Ericsson, Krampe, & Tesch-Römer, 1993); the ultimate origin of that motivation remains unclear.

Three leading approaches

Consideration of the above issues has given rise to the following leading approaches, all of which have specific theoretic advantages and disadvantages.

Social glue. Music strengthens social bonds, cooperation, and empathy (Kirschner & Tomasello, 2010). When groups of people participate in musical activities, they share emotions including a feeling of belonging: Steinbeis and Koelsch (2009) demonstrated that listening to music activates brain areas for mental state attribution. But it is not immediately clear why music should have this "power." An evolutionary explanation breaks down into two stages. In the first stage, the social functions of music emerge accidentally as a result of random genetic mutations. In the second stage they are selected for—perhaps because groups of cooperative individuals are less likely to go extinct (cf. Nowak, 2006).

Mate selection. Darwin (1859) proposed that music is analogous to the plumage of male birds: males use musical displays to attract females for mating, and females evaluate the reproductive fitness of males via their musical displays. The sexual-selection hypothesis (Miller, 2000) predicts that the musical abilities of men should be superior to those of women, but if such differences are observed, they are more likely due to gender roles, sexism and patriarchy (Lindsey, 2015); most famous people (artists, politicians, sportspeople, entrepreneurs and so on) are men. Empirical studies on the sexual partner choices of modern women did not include musical performance skills in lists of relevant criteria (Bereczkei, Voros, Gal, & Bernath, 1997; Buunk, Dijkstra, Fetchenhauer, & Kenrick, 2002; Scheib, 2001).

Motherese. Musilanguage may be none other than *motherese*, a playful game of sound and gesture shared by mothers and infants in all cultures (Dissanayake, 2000). If so, motherese could represent the main origin of both music and language (Fernald, 1992). Trehub (2001) documented the remarkable musical abilities of infants and the role of motherese in regulating infant arousal. She theorized that ancestral mothers who spent more time and energy on motherese also invested more resources into raising children, thereby increasing their probability of survival. That investment in turn increased the probability that the next generation of mothers would use and develop motherese. Fitch (2006) proposed similarly that music could have emerged from mother–infant interactions.

The evidence that motherese is an adaptation is strong, because the theory has a clear evolutionary–biological foundation. Motherese emerged as the brain became larger and upright gait became more common. Both developments made birth more difficult and dangerous, leading to earlier births and more fragile infants (Dissanayake, 2000) requiring obstetric assistance (Rosenberg & Trevathan, 2002). Motherese was especially important for infant survival during the first three months, sometimes referred to as the "fourth trimester," when the infant is most fragile (Jennings & Edmundson, 1980). After that, in ancient or nomadic societies alloparenting took over (Hrdy, 2011) and the infant learned to interact with multiple carers.

Motherese would have evolved over 100,000 years ago, in the Middle Paleolithic (Middle Stone Age). Mothers and carers used motherese to control children while foraging (Falk, 2004). Infants and caregivers co-evolved, becoming more skilled in mutual communication—including mutual knowledge of physical/emotional states and development of social/linguistic skills. In the past 100,000 years, behavioral changes were predominantly cultural in nature (Flinn, 1997); the musically relevant biology of *Homo sapiens* changed relatively little (Caspari & Lee, 2004; Mekel-Bobrov et al., 2005).

Chuckrow's theory of music's prenatal origins

Existing theories of music's origin do not clearly or directly explain what motivated (and still motivates) humans to invest so much time, energy, and resources into musical behaviors in the absence of clear survival/reproduction benefits. Nor do they clearly or directly explain the characteristically strong and transcendental nature of much musical emotion.

Chuckrow (1965/2012) proposed (1) that musical sound patterns such as rhythm and melody are based on the auditory environment of the fetus such as the sound of the mother's voice, heartbeat, footsteps, breathing and digestive sounds. On that basis, and citing published evidence that maternal and fetal hormones form a mutual pool, he proposed (2) that the emotions evoked by music are based on maternal emotions associated prenatally with those sound and movement patterns.

Chuckrow's first proposal is consistent with everyday observations about universal structural features of instrumental as well as vocal music. A moderate tempo corresponds to typical heartbeat and walking rates, the durations or inter-onset intervals of melodic tones correspond to the durations of speech syllables, the mean fundamental frequency and ambitus of melodies correspond to the mean fundamental frequency and range of the human voice, phrase lengths in music correspond to phrase lengths in speech, and so on.

Chuckrow's second proposal is consistent with Mastropieri and Turkewitz (1999), who demonstrated that neonatal responsiveness to vocal expressions of emotion is based on prenatal experience. It is also consistent with the remarkable strength and transcendental nature of the emotions evoked by music as documented by Gabrielsson and Bradbury (2011). The power of musical emotions invites us to compare them with the experience of falling in love, which would support the partner-selection theory of Darwin and Miller. We might also expect a fetus or infant to experience the fetal/infant counterpart or precursor of strong emotion in the presence of the mother, reflecting the strong motivation of the infant to maintain maternal proximity to promote its own survival.

To understand Chuckrow's theory, some physical, biological and psychological background is necessary. The uterine environment, including amniotic fluid, attenuates energy at higher frequencies; Abrams et al. (1998) found that attenuation increased at about 5 dB per octave between about 300 and 2500 Hz. The average fundamental frequency of a typical female speaking voice lies near or somewhat above 200 Hz (Traunmüller & Eriksson, 1994). Thus, the fetus perceives the fundamental frequency of maternal vocalizations with almost no attenuation, whereas higher harmonics are increasingly damped. If adults can discriminate several partials in typical harmonic complex tones (Plomp, 1964), the fetus can perceive only a few, consistent with the importance of the "perfect" octave, fifth and fourth intervals in music (which occur between the first four harmonics). The most salient feature of a melody is its contour—not the exact pitches (Dowling, 1978). In that respect, melody is similar to the fundamental frequency contour of low-pass filtered female speech. Even the frequency range is similar; the range of a typical melody corresponds more closely to a female than to a male voice (Teie, 2016).

Fetal responses to diverse stimuli including foreign male and female speech have provided evidence of fetal attention, memory and learning (Kisilevsky et al., 2009; Moon & Fifer, 2000). The attention of a human or animal observer may be attracted by stimulus patterns that are different from usual or expected patterns (surprise) or parameters that change relatively quickly or considerably (Jonides & Yantis, 1988; Miller, 1989). In low-pass-filtered maternal vocalizations as perceived by the fetus, pitch may be perceived to change more or faster than timbre (from one voiced speech sound to the next), so pitch is more perceptually salient. In the same sounds perceived after birth by the infant without low-pass filtering, timbre may be perceived to change faster than pitch, so phonemes become more salient and the infant starts to acquire lexical knowledge.

Chuckrow's theory suggests that the emotions associated with prenatally audible sound and movement patterns are a rich source from which to create sonic art. Today, composers have indirect access to this source (modified by music experience and history) whereas painters do not. Chuckrow's theory also has the potential to explain several missing links and open questions in existing approaches to the origin of music. Consider the following questions and the answers that his theory offers:

- Why does music evoke transcendental emotions? Musical emotions may be based on biochemical correlates of fetal and infant emotions during interaction with the mother. The fetus and infant depend on the mother for survival, so the relationship has an existential quality. Music's transcendental emotions may thus reflect the infant's instinctive motivation to engage in attachment and bonding behaviors.
- Why is music linked to skill acquisition in various domains? Infants acquire skills playfully, in active interaction with (or in the passive presence of) the mother or caregiver. Without that interaction or presence, playful exploration is inhibited (Sorce & Emde, 1981). The motivation to acquire musical skills is linked to the emotions evoked by sound/movement patterns that are similar to patterns perceived prenatally.
- Why does music promote social cohesion? If music's origin is prenatal, then it is associated with the experience of oneness with the mother, similar to the experience of oneness in tightly knit social groups. The sonic vocabulary of motherese (Papoušek, Papoušek, & Symmes, 1991) could be based on prenatal experience (Mastropieri & Turkewitz, 1999). Maternal interactions and motherese are the first context in which infants acquire social skills including elementary morality (turn-opening versus turn-closing, approval versus disapproval) (Papoušek et al., 1991).
- Why do children have innate musical expertise? In early hunter-gatherer societies, an infant's survival depended crucially on its ability to interact appropriately with its mother or caregiver. That ability depended on how the infant perceived the mother's physical and psychological state. That can explain why auditory acuity approaches adult levels at birth (Hepper & Shahidullah, 1994), whereas visual acuity matures 6 months later (Sokol, 1978). The ancestral infant's ability to track maternal sound and movement patterns, learned prenatally, may have been vital for survival.
- Why are humans motivated to devote considerable resources (time, energy, creativity, money) to music although it does not directly promote survival or reproduction? The motivation to listen to and make music may be partly based on associations between musical sound/movement patterns and the mother as perceived by the fetus (Chuckrow, 1965, 1998), and, on that sonic-gestural-emotional foundation, motherese as a form of attachment behavior—the infant's motivation to maintain proximity to and communication with the mother or caregiver (Bowlby, 1969).

Fetal and infant "consciousness"

Empirical research in developmental psychology suggests that neither the fetus nor the infant is capable of reflection—a uniquely human ability that emerges gradually during childhood (Bretherton & Beeghly, 1982). But reflection is a prerequisite for neither perception nor attention; indeed, most perception and attention is not reflected upon (Merikle, Smilek, & Eastwood, 2001). On the contrary, most perception by humans is without awareness (Merikle et al., 2001), which of course also applies to non-human animals. It is truer to say that perception generally involves active interaction with the environment (Gibson, 1979). Selective attention may be operationally indistinguishable from evaluation (liking or preference). In these respects, the fetus may be comparable with mature non-human animals.

Given this background, we will use the word "experience" (in inverted commas) as a shorthand for the fetal neurophysiological foundations of later memory and conscious experience. If we consider the ecological–evolutionary affordances of mother–infant interactions and the infant's existential dependency on maternal motivation and behavior, we can imagine how the fetus would "experience" the world if it had consciousness. An infant in a state of quiet wakefulness in the presence of its mother might "experience" primitive correlates of emotions such as admiration or worship; in her absence, fear, loneliness or frustration. There is no empirical evidence for such emotions, but their existence would be consistent with approaches based on embodiment and enaction, in which emotions are not confined to the "mind" or "cognition" but are dynamically inseparable from their corporal, social and environmental context (Schiavio, van der Schyff, Cespedes-Guevara, & Reybrouck, 2016).

The psychology of the late fetus is no different from the psychology of the newborn. Birth may be considered a *physiological* switch that radically changes circulation and turns on breathing and digestion, but it is not a *psychological* switch that changes the basic nature of perception, cognition and emotion. We therefore predict a continuity between prenatal and perinatal behavior and "experience." Given the frequency with which the fetus "experiences" sound and movement patterns corresponding to the internal sounds and movements of the mother's body—along with their emotional correlates—we predict that those perceptual and emotional patterns and connections affect brain development such that similar stimuli in later life trigger similar emotions (Hepper, 1996).

Our theory predicts associations between sound–movement patterns and emotions in all prenatally hearing animals. Music as we know it emerged when early humans started to notice the relationship between sound–movement patterns and the feelings they evoke, and then deliberately repeated the actions that produced the patterns with the aim of reproducing the emotions in ritual situations. Reflective consciousness and/or theory of mind (Livingstone & Thompson, 2009) were co-prerequisites for this behavior, which is typical not only of music but also of art, religion and ritual in general, and emerged during the prehistoric "cultural explosion" along with human creativity (Mithen, 2005).

The motivation to make and listen to music

That early humans possessed the physiological prerequisites for music is clear from protomusical behaviors of other primates such as chimpanzees (Merker, 2000). But what motivated them to make music? A learning/behaviorist theory of infant attachment based on classical and operant conditioning (e.g. Dollard & Miller, 1950) is relevant: the observed behaviors of the fetus or infant can be understood in a stimulus-response approach. If a fetus repeatedly perceives specific sound and movement patterns followed by specific emotional changes triggered by hormones in the maternal blood, as for example when the mother is surprised or shocked, it will be conditioned to associate these stimulus patterns such that in the future, similar patterns will be associated with similar emotions.

This idea can explain why sound and movement patterns in music evoke strong emotions. Emotions are experiences that accompany the appraisal of a stimulus or an action tendency (Frijda, Kuipers, & Ter Schure, 1989). This definition suggests that the fetus (unconsciously) "experiences" emotion when evaluating its mother's changing state, and the infant "experiences" emotion when maintaining proximity to the mother during exploration or play.

In the terminology of Parncutt (2009a), the *mother schema* is evoked. Universal behavioral examples include infant-directed song (lullabies), rocking, motherese and childhood dance (Konner, 1974, cited in Mehr & Krasnow, 2017). The mother schema can also explain "How can an infant know that a parent is, in fact, attending to him?" (Mehr & Krasnow, 2017, p. 677). To evaluate current maternal state, the infant compares learned knowledge about maternal speech and movement patterns with real-time perception.

Unlike their primate relatives, human infants cannot cling to parents or locomote toward caregivers until several months after birth. Infant vulnerability explains why mother–infant proximity and communication are so important, especially in uncertain or dangerous situations, and hence the evolutionary emergence of motherese as a form of musilanguage—a mixture of metalanguage and metamusic (Brown, 2000). The motivation to make or listen to music may be a by-product of this and other adaptive behaviors. For Ainsworth (1973) and Bowlby (1969), attachment is a deep emotional bond that can be maintained for long periods of time, regardless of physical separation, and infant–mother attachment is the strongest such bond; the so-called "music instinct" (Mithen, 2009) is similarly resilient and long-lasting. The importance of prenatal sound for maternal attachment was famously demonstrated by Lorenz (1935), who trained young geese to follow him when he made a quacking sound.

The human motivation to make and engage in music is also related to tool use. The effort that goes into learning to use a tool (its behavioral cost) must balanced by benefits (Croxson, Walton, O'Reilly, Behrens, & Rushworth, 2009). A musical instrument is a tool whose cost is practice and whose benefit is mysterious emotion that promotes social bonding and group cohesion (Kirschner & Tomasello, 2010). The process by which early humans "performed" "music" may have involved a combination of operant conditioning and conscious reflection (Parncutt, 1993, 2009a). Prenatal classical conditioning can explain why early humans experienced special feelings of mysterious origin in connection with certain patterns of sound and movement. They then reflected on that experience, and tried to recreate it (operant conditioning). Prenatal conditioning can explain why musicians devote so much time and effort to practice for so little explicit reward (Ericsson, 2004).

Prenatal versus postnatal perception of sound/movement patterns

Which sound patterns had more influence on music—prenatal (as perceived by the fetus) or postnatal (by the infant or child)? We propose that prenatal patterns are more important for the following reasons:

1. Prenatal sounds are dominated by the internal sounds of the mother's body, which correlate with her physical and emotional state, upon which the survival of the fetus depends.
2. Prenatally audible rhythms and musical rhythms have a similar distribution of pulse periods (frequencies), centered on roughly 100 beats per minute. Rhythms of this kind are more often audible and salient before birth (as heartbeat and walking sounds) than after birth.
3. Dance-like rhythms are similar to maternal footsteps and associated fetal movements, but postnatally heard rhythms are not necessarily linked to movement. The link between ritardando and physical movement (Kronman & Sundberg, 1987) could be learned either before or after birth, but a perceptible relationship occurs more frequently and more saliently before birth.
4. The maternal and fetal heartbeats combine to create something similar to meter or polyrhythm (Chuckrow, 1965). In everyday (postnatal) life, non-musical examples of such combinations are possible when any two isochronous sequences are heard at the same time with different tempos. But such everyday rhythmic combinations are less likely to

happen or to be perceived as meaningful. For the fetus, any sound pattern that is linked to the physical or emotional state of the mother, such as the sound of her (and its own) heart, has survival implications. Meter may also be based on a combination of (faster) heartbeat and (slower) respiration, or heartbeats and footfalls (Teie, 2016). Again, such patterns are more salient prenatally than postnatally.

5. For adults, rhythm perception and associated movement implications (proprioception) involve audition (Chen, Zatorre, & Penhune, 2006; Phillips-Silver & Trainor, 2007) more than they involve vision (Repp & Penel, 2004). Prenatal learning provides a parsimonious explanation for the dominance of audition in rhythm perception and the tendency for auditory (but not visual) rhythms to imply or invoke movement.
6. The phrasing of speech—vocalizations interrupted by breathing—is more perceptually salient for the fetus in the prenatal environment than it is for the infant in the postnatal environment. Prenatally, higher frequencies are filtered out (so changes in pitch are more salient relative to spectral envelope or timbre) and breathing is directly audible. Consistent with this argument, phrasing plays an important role in the perceived structure of instrumental music and its expressive quality—not only for wind instruments, in which phrasing corresponds to the performer's breathing, but also for non-wind instruments such as the piano (Palmer, 1996).
7. The musical abilities of infants (Trehub, 2001) are comparable with those of adult non-musicians, and more sophisticated than necessary for successful communication and bonding with the mother. Protomusical patterns may be learned prenatally and augmented during exchanges of motherese.
8. The hypothesis that the basic sound and movement structures of music were originally prenatally learned is consistent with the mysterious abstract meaning of music in comparison to that of other arts and its universal association with religion or spirituality. By contrast, the meaning of a painting is more closely tied to the appearance of objects in the everyday environment.

The origin of specific music-structural elements

A strength of the present theory is its ability to explain specific music-structural elements. Both Chuckrow (1965/2011) and Parncutt (e.g. 1993) systematically considered structural similarities between musical elements and the internal sound patterns of the human body as perceived by the fetus. Both cited diverse empirical literature on prenatal perception, learning and memory. Both attempted on that basis to explain why music plays such an important role in every known human culture, arousing specific emotions. Both considered fetal hearing and pertinent stimuli including maternal emotions, breathing, voice, digestion, gross movement and cardiovascular sounds, and both observed that these stimuli corresponded to analogous elements of rhythm, harmony and melody in music. The theories of both authors were independent of whether the fetus has any kind of consciousness; it clearly lacks reflective consciousness in the everyday adult sense.

Rhythm, heartbeats and footsteps

Unlike speech, most music is *isochronic* (Fitch, 2006)—heard relative to a real or imagined series of events called the *tactus* (Lerdahl & Jackendoff, 1983). What is the origin of this fundamental difference between music and speech? Parncutt considered the effect of both maternal footsteps and maternal heartbeat on the fetus and its later rhythmic perception.

Chuckrow considered both the fetal and maternal heartbeats. He mentioned maternal walking as a stimulus, but initially did not write about its specific musical correlate. Later, he related prenatally perceived maternal footsteps to the beat in music, especially popular music (Chuckrow, 1995, 1998).

Chuckrow's assumption that the fetus can hear its own heart is reasonable given that fetal heartbeat can be heard by a gynecologist with a regular stethoscope from about 20 weeks gestation (fetal phonocardiography; Smyth & Farrow, 1958). Both sides of the fetus's eardrums are immersed in amniotic fluid, a good conductor of sound. It is also possible that the fetus proprioceptively feels its heartbeat.

In musical rhythm, one or more isochronous pulse trains combine to create either meter (e.g. Western) or polyrhythm (e.g. African) (Arom, Thom, Tuckett, & Boyd, 2004; Parncutt, 1994). Since fetal heart rate is roughly twice that adult (maternal) heart rate, and assuming the fetus hears both (the slower maternal heartbeat being louder), Chuckrow argued that the combination of the two heartbeats could explain both meter and polyrhythm. Since the 2:1 ratio is very approximate, the idea is consistent with meters such as 3/4 or polyrhythms such as 2 against 3. Chuckrow presented combined maternal and fetal electrocardiograms from Larks and Dasgupta (1958) showing the three main types of maternal/fetal rhythms according to his sources at the time, namely, 1:1, 1:2, and 1:3.

Chuckrow's approach can explain why the slower of the two pulses in a duple pattern typically has a period of about 600 ms; it corresponds roughly to the maternal heartbeat. The faster pulse corresponds to the fetal heartbeat. Of course, musical tempo and tone-duration distributions are also influenced by tempo or duration distributions in other bodily movements.

Chuckrow speculated about a possible relationship between changes of combined heartbeat rhythms resulting from changes in the maternal emotions, as repeatedly experienced by the fetus, and the excitement or arousal that one experiences when listening to music when the tempo increases or relationships between rhythmic strata develop. The idea is plausible considering that the fetal heart rate depends on both maternal arousal (Collings & Curet, 1985) and maternal emotional state (Allister, Lester, Carr, & Liu, 2001).

Consistent with Chuckrow, Van Leeuwen et al. (2009) speculated that the "mother's special awareness to the unborn child may … be reflected by fetal–maternal interaction of cardiac activity" (p. 13661) based on evidence for coupling (phase locking) between fetal and maternal heart rates at the following ratios: 3:2 (46% of cases), 5:3 (23%) and 4:3 (17%). Other combinations included 2:1, 5:4, and 7:4. Coupling happened more often at higher maternal respiratory rates and hence at higher maternal and fetal heart rates.

Western meters combine two or more consonant or compatible pulses. Their rates have a simple ratio, and they are phase-locked. For example, 2/4 meter combines a ¼-note pulse with a ½-note pulse; the music is perceived relative to both pulses simultaneously. Other rhythmic constructs are more complex or ambiguous. Consider the Afro-Cuban *clave*. When notated as a series of durations or inter-onset intervals, a typical clave pattern might be 3+3+4+2+4=16. Another well-known complex rhythmic pattern is the (Sub-Saharan) African "diatonic" rhythmic cycle, so called because its duration pattern (2+2+1+2+2+2+1=12) corresponds to the interval pattern of a Western major scale. Rhythms of this kind are typically heard relative to one of two different and (for a Western ear) conflicting background pulses (e.g. 4+4+4=12, or 3+3+3+3=12). The foreground rhythm heard in such music includes short isochronous sequences that last for three to four events and then "skip a beat" before returning in the next cycle. It would be far-fetched to posit a direct link between such rhythms and the prenatal environment. This musical phenomenon can nonetheless be compared with heart-rate variability, in which the time intervals between almost equally spaced pulses rise and fall in a partly predictable fashion.

Research on the categorical perception of musical rhythm is also relevant. Neither an exact frequency ratio nor phase locking are prerequisites for perceiving a pattern such as 1:2 or 2:3 or a meter such as 2/4 or ¾ in a categorical sense (Clarke, 1987). In music, we perceive such patterns and relationships even when timing is audibly variable.

Parncutt claimed that the fetus is sensitive to the emotional state of the mother because that sensitivity helps the infant to survive in a dangerous world. Infant survival is enhanced if the fetus gets a head-start in learning to monitor the mother's emotional state in different ways, for example by tracking the sound patterns produced by her voice, heart, stomach and feet, as well as hormonal changes. As an example, the mother may hold her infant on the left side, allowing the audible heartbeat to calm it (Salk, 1973); an ecological argument of that kind could explain the origin of handedness in humans (Huheey, 1977).

Ritardando

Parncutt related the slowing down of music, enhancing a feeling of finality, to the manner in which footsteps decelerate as a destination is approached. Chuckrow considered sinus arrhythmia, or changes in heart rate with inhalation and exhalation: if musical phrases correspond to maternal breathing, that might explain why musical phrases tend to speed up at the beginning and slow at the end (Penel & Drake, 1998).

Melody

A theory of music's origins must explain *song* before it explains instrumental music. It must also explain why infant-directed song has universal structural features and is universally used by parents to calm infants (Mehr & Krasnow, 2017). Parncutt related the rising and falling pitch of a musical melody to the maternal speaking voice as perceived by the fetus. Without mentioning the words *melody* or *phrasing*, Chuckrow discussed the correspondence between rising and falling intonations and syllabic articulations of human speech and "tonal patterns in music." Chuckrow also related the presence of words in sung music to their verbal counterparts in the fetal environment. Parncutt related musical phrase boundaries to maternal inhalations; Chuckrow mentioned maternal speech and breathing as a stimulus but did not specifically write about its musical correlate of phrasing.

Harmony

Parncutt related musical harmony to prenatally audible harmonics in the mother's vocalizations. Chuckrow additionally speculated that the immersion of both sides of the fetal eardrum in amniotic fluid would lead to increased harmonic distortion of the mother's voice, thereby producing audible harmonics in response to a pure tone, such as the fundamental frequency of the maternal voice when the higher partials are masked.

Harmonic generation is typical for non-linear transducers—here, the eardrum and inner ear (Cooper, 1998). The human ear has evolved to work optimally with air and not with liquid (amniotic fluid) on both sides of the eardrum. Optimum aural function involves a series of factors (Petit, El-Amraoui, & Avan, 2013) including sensitivity to a very wide range of intensities, a compromise between temporal and spectral sensitivity in the recognition of typical or dangerous environmental sound sources (according to the physical constraint known as the *uncertainty principle*; Stewart, 1931), and physiological suppression of non-linear distortion products including harmonic distortion. The presence of a different medium (amniotic fluid) would increase harmonic distortion by comparison with postnatal perception. Accordingly, louder maternal speech, which usually reflects more intense emotion, would generate disproportionately greater harmonic distortion in the fetal inner ear, thereby increasing the probability of perceiving higher harmonics. Chuckrow argues that this effect is consistent with increased harmonic complexity in music being associated with increased emotional intensity.

The origin of musical intervals corresponding to ratios from the harmonic series can also be explained without considering non-linear generation of harmonic overtones of a pure tone. The fetus can usually hear a few lower harmonics of maternal vocalizations (Hepper & Shahidullah (1994). The human voice is like a musical instrument in that the intensity of higher harmonics increases relative to lower harmonics as overall intensity and vocal-fold tension increase (Sundberg, 1991). That could explain relationships between emotional intensity in music and escalations of harmonic complexity in the repetition of musical ideas (cf. Huron, 1992).

Counterpoint

Chuckrow (1965/2012) compared counterpoint in music with the independent meandering of the pitch of maternal formants, two to four of which are usually identifiable in natural human speech. Parncutt (1989) asked whether the fetus hears several spectral pitches in a single harmonic complex tone (similar to later perception of harmony) before learning to assign a virtual pitch to the fundamental and compared this phenomenon with the perception of Western harmony.

Biological and behavioral time delays

Parncutt (2009a) considered the time delay between maternal behavioral changes (such as changes in movement, vocalization and heartbeat in response to a surprise) and corresponding hormonal changes that could be shared by the fetus, invoking a classical conditioning paradigm in which a predictive conditioned stimulus is paired with a later unconditioned stimulus. The time delay between maternal and fetal biochemical responses was considered in more detail by Parncutt and Sedlmayr (2014).

Chuckrow similarly considered the time lag between cause and effect as hormones accompanying changing maternal emotions pass from the maternal into the fetal blood. A change in the mother's emotional state may result in an immediate change in her heart rate, but the fetal heart rate would not yet change because the hormones associated with maternal emotions cannot instantaneously migrate across the placenta. Chuckrow also realized that a solely maternal change would affect the rhythm produced by the combination of the two heartbeats. The change might forewarn the fetus of oncoming maternal hormonal changes, giving it a chance to prepare or adapt. After birth, musical rhythm changes may evoke similar hormonal or emotional patterns.

Evaluation of Chuckrow's original manuscript

A transcription of Chuckrow (1965) is available in the Supplemental Online Material. Errors in punctuation and grammar in the original document have been fixed, clarifications have been added in square brackets, and a few minor alterations in sentence structure were made without changing the original meaning. Section headings, typography, and references were brought closer to the APA style, and other minor stylistic changes were made.

The original typewritten manuscript (available on request in pdf format) was written when Chuckrow was a graduate student at New York University from 1962 to 1969. It includes handwritten additions made in the year 1967, when the author was working on his Ph.D. thesis in experimental physics at New York University. In the following, we critically address selected points from the original manuscript, drawing on relevant current literature.

In his abstract, Chuckrow wrote:

> We advance a mechanism by which music evokes feelings, namely, that music revives learned, neurohormonal responses to consistently recurring prenatal stimuli, and these responses are accompanied by emotions.

The word *mechanism* suggests that the theory is based in the physical world, implying that issues of consciousness are not relevant. The fetus certainly has nothing comparable with adult reflection, and even if it did, it may be impossible for science to investigate that—just as it may never be possible for humans to know what it is like to be a bat (Nagel, 1974).

In a purely physical (physiological) approach, we can consider the effect that environmental stimuli have on the developing fetal brain. In that sense, we can speak of learning. Neural responses to stimulus patterns in later life might resemble prenatal neural responses to similar patterns, but conscious reflection on the emotions carried by these responses is not possible until later. In Chuckrow's words:

> In the case of music, the connection between the sounds we hear and the feelings they evoke is much harder to state. This difficulty suggests that music evokes responses formed during a very early period of life when communication by means of verbal exchange is absent.

The prenatal learning hypothesis is one of two possibilities. The other possibility is that the origin of these feelings is genetically transmitted. If Darwin's theory of the origin of music were correct (and it could be correct in part), music was used by men to demonstrate their paternal suitability for women looking for a sexual partner. If the theory that music is a kind of social glue is correct, music evolved because it improved cooperation within groups.

> It is therefore unlikely that smell, taste or temperature play an important role.

Later research showed that this statement was incorrect. The fetus can smell and taste before birth and there is also transnatal learning of smells and tastes. But this error in no way undermines Chuckrow's main thesis.

Chuckrow listed many sounds that are audible to the fetus but omitted the sound of maternal footfalls. That was a curious omission given that a "rap on the side of a tub in which a pregnant mother was bathing" is audible to the fetus. To our knowledge, no empirical study has directly investigated the audibility of footfalls for the human fetus.

> At present, little is known specifically of the immediate or long-range effects on the fetus of the mother's emotions, although there is considerable evidence that the mother's emotions do affect the fetus.

This is an interesting prediction that was abundantly fulfilled in later years in research on the postnatal effects of prenatal depression (Field, Diego, & Hernandez-Reif, 2006).

> The possible effects of variations in electric potential to which the fetus is subjected have not, at present, been investigated. This is an area of investigation that may prove to be important. For example, the rhythmic variations in the potentials associated with cardiovascular contractions may directly influence or even establish rhythmic variations of electric potentials in the fetal brain.

This more speculative idea can be omitted from Chuckrow's argument.

> There is an opportunity for the fetus to learn to adjust to the chemical changes before they come, rather than having them come as an unexpected jolt.

This claim is surprisingly similar to Parncutt's classical conditioning approach.

> If such patterns are repeated with sufficient frequencies, they may become an object for fetal learning.

This assumption was also made by Parncutt. The patterns in question must happen many times (for each individual fetus), and the patterns must also be similar (for different fetuses), if they are to make their way into an emerging musical culture. Episodic learning (i.e. without repetition) would be insufficient.

When discussing rhythm, Chuckrow notes later that:

> Moreover, in music, this beat, which is produced by an instrument such as a drum, or a plucked bass viol, has a sound which resembles that of a pulsing heart.

In a similar vein, Parncutt (1989) claimed that downbeats in music usually sound lower in pitch or deeper in timbre than upbeats. But there are exceptions, raising the possibility that this idea is culture specific. On this topic it would be interesting to investigate experimentally whether the maternal heartbeat sounds lower or deeper to the fetus than its own heartbeat.

> Some of the feelings evoked by music are a sense of buoyancy, a sensation of bathing in a warm fluid…

Imagery involving water or a feeling of floating or weightlessness can also be found in descriptions of strong experiences of music (Gabrielsson & Bradbury, 2011).

> The speech of a pregnant mother would, therefore, be accompanied by changes in pressure and force on the fetus, causing it to be moved in patterns related to that speech. Thus, supplying this motion ourselves intensifies the suggestion of the prenatal state.

The tendency to move to music can be explained more simply, as Parncutt realized. When the mother walks, the fetus simultaneously hears her footsteps and experiences large periodic body movements (vertical accelerations and decelerations). In music, rhythmic stimuli that are relatively constant (such as when the mother walks for a long time on flat ground) are associated with regular synchronized body movements.

> Can patterns in music be more definitely linked to patterns in prenatal stimuli?

It would be interesting to ask this question empirically in collaboration with an ethnomusicologist considering a wide range of diverse cultures (cf. Teie, 2017).

> To what extent does the fetus hear, and what is the qualitative nature of any inherent differences in hearing before and after birth?

Later research demonstrated that the fetus hears well enough for the purpose of this theory. Moreover there is no qualitative difference between hearing before and after birth except that prenatally audible sounds of both internal and external origin are low-pass filtered (Abrams et al., 1998).

The following sentences concisely sum up Chuckrow's main point:

> Let us examine the hypothesis that music is an organized pattern of sounds constituting a synthesis of prenatal stimuli and that recognition of these patterns revives modes of neurohormonal activity corresponding to that produced by prenatal stimuli. In the case of an adult, this activity would be experienced as emotions.

Historical context

Speculations about music's origin have a long history. Many ideas were published during the late 19th and early 20th centuries within the emerging discipline of music psychology, especially in Germany (e.g. Stumpf, 1911/2012). The topic was avoided after the "cognitive turn" in psychology and the emergence of music psychology within North American psychology (1960s; Baars, 1986). Instead, psychology became more empirical, quantitative and materialist, reacting against earlier speculative, qualitative and phenomenological traditions. The 1970s "cultural turn" in the humanities inspired the new musicology of the 1980s (Fulcher, 2011), which in turn led to a cultural turn in music psychology in the 1990s (Allesch & Krakauer, 2006), expanding the range of methodological and epistemological approaches. In this context, two empirically, less tangible topics were revived, namely, musical emotion and musical origins. Mainstream researchers again asked why music evokes strong emotions and how music might have originated.

Chuckrow developed his ideas on the nature and origin of music as a graduate student at the Department of Physics, New York University (NYU), between 1962 and 1969. He remembers spending weeks in the NYU medical library researching the relevant literature on prenatal learning and development before writing a draft paper in 1965. He was and still is unaware of anyone else having made a similar suggestion, then or earlier.

From 1967 to 1969, Chuckrow was carrying out experimental research for his Ph.D. thesis. In 1967, he showed his paper on the prenatal origin of music to his thesis advisor, H. Henry Stroke. In addition to being a physicist, Stroke was a musician and taught a course in the physics of sound and music at NYU. Stroke advised Chuckrow not to publish the paper because its unconventional content might adversely affect his reputation as a physicist. Chuckrow accepted Stroke's advice until 2012, when he linked the paper to his website at www.historicaltuning.com.

Chuckrow received his Ph.D. in physics in 1969 on the hyperfine structure and isotope shift of Bismuth 207 (Chuckrow, 1970; Chuckrow & Stroke, 1971). At about the same time, he contacted a number of researchers in the field of prenatal learning with the idea of working on one of their research projects. Most rejected the idea, explaining that although including a physicist in the research could be beneficial, the idea could not be funded. The one exception was psychologist Gilbert Gottlieb (1929–2006), known for his theory of probabilistic epigenesis (Gottlieb, 2007), according to which traits do not develop along predetermined path but rather through an interaction between genes and environment. At the time, Gottlieb was working on embryonic learning in ducks, and he invited Chuckrow to visit him in Raleigh, North Carolina, in the hope that they could apply for a grant together. They spent a day writing the application, but the grant did not materialize.

Chuckrow's ideas about the origin of music lay dormant as he taught physics at NYU from 1971 to 1973, The Cooper Union from 1972 to 1973, and two high schools from 1973 to 1977. He first referred to these ideas in his teaching in the summers of 1977 through 1980 in a physics course entitled "Sound and Music" at NYU. Each course included one or two lectures on the prenatal roots of music. From 1978 to 2005, he taught various physics courses including the physics of sound and music at The Fieldston School in the Bronx, New York, each time including presentations on the prenatal roots of music. The aim was to explain the main structural elements of music—rhythm, counterpoint, and harmony—in terms of prenatal stimuli and also to consider why changes in rhythm evoke excitement. The theoretical explanations were supported by diverse musical sound examples.

Parncutt was a Ph.D. student at the University of New England in Armidale, New South Wales, Australia from 1981 to 1986. From late 1982 to the end of 1983, he was guest researcher in Ernst Terhardt's laboratory at the Technical University of Munich, Germany. The idea that music might have a prenatal origin first occurred to Parncutt when considering Terhardt's (1974) claim that the perception of virtual pitch (the pitch at the fundamental of a harmonic complex tone) is based on learning (Parncutt, 1986). Terhardt theorized that the auditory system acquires information about the harmonic series from the audible harmonics of complex tones to which it is exposed—especially voiced speech sounds. This learning process must happen early in life, otherwise a complex tone would sound like a simultaneity of pure tones—perhaps even like a musical chord. The process should be well advanced before birth, to facilitate perinatal interaction between mother and infant and enhance the infant's chances of survival. This point may explain why human hearing starts to function so early—some 20 weeks before birth (Hepper & Shahidullah, 1994). During those 20 weeks, the fetus acquires and processes a wealth of information about perceptual patterns; indeed, without these perceptual and cognitive processes, the auditory system would not develop properly (Pujol & Hilding, 1973). The adaptive value lies in the existential importance of the mother–infant relationship.

Discussion: What makes a good theory?

Our theory is plausible because it is based on adaptive behaviors, assumed to have emerged from life-and-death situations. In general, human infant survival depends on the ability of both infant and mother to monitor and respond to each other's physical and emotional state (cf. Murray & Trevarthen, 1986). The proposed adaptations in infant–carer behavior were responses to high infant mortality rates, which were (and still are) much higher than mortality rates due to violence. Today, global child mortality is about 9 million per year; the main cause is infectious disease (pneumonia, diarrhea, malaria; Black et al., 2010). The global death rate due to violence is an order of magnitude lower. In today's hunter-gatherer societies, "Not only are mortality rates much higher [than today] in the Hiwi, they are disproportionately higher among infants, children, and young adults [...] Infant mortality is high, and death rates reach their lowest levels around the age of sexual maturity" (Hill, Hurtado, & Walker, 2007).

Uniquely human behaviors such as music may best be explained on the basis of uniquely human attributes. By comparison to other animals including primates, human infants are fragile and helpless (larger brains meant earlier births) and take a long time to mature (larger brains take longer to "program;" Hill & Kaplan, 1999), suggesting that the foundations of uniquely human behaviors may be found in infancy and childhood.

Beyond these points, any scientific theory must satisfy a number of general criteria or desiderata. These include a foundation in observable evidence, concrete predictions that are consistent with that evidence, falsifiability, hierarchical structure (submechanisms), overall amount and strength of evidence in comparison with competing theories, and parsimony. In the following, we evaluate our theory by considering each of these points in turn.

A good scientific theory is based on *observable evidence*. In comparison with other theories of music's origin, a prenatal approach involves relatively many empirically accessible phenomena, including the acoustic environment of the fetus, the psychological abilities of the fetus (perceptual, motor, cognitive, emotional), the acquisition of musical skills by children, the specific emotions evoked by music, and commonalities and differences between musics of the world. Our theory is based on fetal abilities to perceive and learn that have been repeatedly confirmed in empirical studies. Consider, for example, the effect of the mother's native language on infant cry (Mampe, Friederici, Christophe, & Wermke, 2009). While a given language group may have typical genetic characteristics (Sokal et al., 1990), it is also possible for any child to be adopted into any culture, learn the language of that culture, and become linguistically indistinguishable from a "native." If a girl in this scenario grows up and has a baby, we can demonstrate that the effect of maternal language on crying patterns is entirely learned. If, however, we wish to test whether rhythm perception is learned from prenatally audible heartbeat or footstep sounds, it may be impossible to empirically separate nature from nurture, because practically all fetuses and infants are regularly exposed to both heartbeat and footstep sounds—as well as music. Nazzi, Bertoncini and Mehler (1998) nevertheless found that "newborns use ... rhythmic information to classify utterances into broad language classes" (p. 756), an ability that is presumably based only on prenatal learning of the characteristic rhythms of the mother's language.

A scientific theory should make concrete *predictions* that are consistent with evidence. This criterion is generally difficult to fulfill for theories of the origin of music, and the present theory is no exception. We might, for example, predict that musicality is promoted by prenatal exposure to sound–movement relationships within the mother's body. Specifically, the offspring of mothers who cannot speak (or speak very little) or cannot move/walk (or move/walk very little) should have inferior musical experience, skills, or potential. That prediction could be tested by interviewing the children of such mothers and comparing results with a control group, but interpretation of the results would be difficult due to inevitable confounds. Regarding emotion, a theory of the origin of music should predict or explain music's mysterious power to "imbue any situation with meaningfulness" and to be "a-referentially expressive" (Fitch, 2006, p. 180). It should also explain why "human music typically occurs in specific *performative contexts*: particular songs or styles recur in specific social contests, especially ritualist contexts stressing supernatural or mystical themes" (Fitch, 2006, p. 179). These observations are evidently consistent with the developmental function and protolinguistic, performative nature of motherese and its relevance for early human infant survival, but it would be difficult to test them quantitatively by comparing predictions with empirical data.

A scientific theory is often considered plausible if it is *falsifiable* (Popper, 1959). All theories of music's origin are problematic in this regard because there is almost no record of what actually happened when "music" was "emerging." In sociological theory, it is not possible to prove causation by performing an experiment in which earlier social conditions are manipulated and later results observed (Rex, 2010). Similarly, we cannot manipulate prehistoric conditions (as independent variables) that may have causally influenced the emergence of music, and then observe and compare the results (as dependent variables). In our case, it not possible to change one aspect of the human fetal environment and study the musical result without simultaneously changing other aspects. Moreover, non-invasive research on fetal perception, cognition, emotion and behavior is still difficult, despite technological progress. Since Chuckrow developed his theory, hundreds of relevant empirical studies have been published. To our knowledge, no empirical finding contradicts his theory, although contradictions are possible, for example in quantitative data on the frequency of occurrence of pitch–time patterns.

A scientific theory may be more testable and falsifiable when it is *hierarchically structured* such that mechanisms can be broken down into submechanisms, leading to a larger number of testable predictions and a higher probability of falsification. A clear hierarchical structure also makes the theory easier for humans to subjectively understand and apply (Hempel, 1965). For example, if we assume that prenatal hearing allows the fetus to acquire information about different sound/movement patterns associated with the maternal voice, heart and feet, an analysis of these different signals and their dependencies on other parameters can account in different ways for different features of musical structures considered in the academic discipline of music theory, including harmony, melody, rhythm, emotion, beat, phrasing, ritardando and counterpoint. In each case, testable predictions may be possible. To our knowledge, no other theory of the origin of music can mechanistically explain diverse music-structural elements.

The evidence in favor of a good theory should be stronger than the evidence in favor of competing theories, and/or the evidence against should be weaker. In real, imperfect, human-driven science, that is how scientific ideas tend to develop (Bryson, 2005; Kuhn, 1962). Comparisons based on objective evidence are ultimately subjective, involving consensus with a scientific community (including peer-review procedures). In practice, this is the only way forward, especially when considering complex, multifaceted issues such as the origin of music.

Another criterion is parsimony, or Ockham's razor. A theory is conceptually parsimonious if a small number of assumptions explain a large number of phenomena. Parsimonious theories are less arbitrary (ad-hoc) easier to support and falsify (Forster & Sober, 1994). The present theory is based on two main assumptions: first, that musical sound/movement structures are based on prenatally perceptible sound/movement structures, and second, that these structures, when considered in the context of fetal–maternal and infant–maternal relationships, can explain aspects of musical emotion. These two ideas are consistent with many universal features of music, including the importance of transcendental emotions, the shared emotions that musicking groups experience, preferences for rhythmic isochrony and synchronicity (entrainment), and the cross-cultural existence of metrical hierarchies and polyrhythms. Parncutt's (2009a) mother schema is consistent with effects of music on pain perception (Hekmat & Hertel, 1993), sport stamina (Copeland & Franks, 1991), and the performance of repetitive work for long periods (Fox & Embrey, 1972). The theory might even explain the idolization of pop stars (Raviv, Bar-Tal, Raviv, & Ben-Horin, 1996) and the universal connection between music and religion, including the many roles that music plays in religious and spiritual practices.

Supplementary Material

Chuckrow (1965) is available as Supplemental Online Material, which can be found attached to the online version of this article at http://msx.sagepub.com. Click on the hyperlink "Supplemental material" to view the additional files.

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