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The developmental origins of musicality

Sandra E Trehub

The study of musical abilities and activities in infancy has the potential to shed light on musical biases or dispositions that are rooted in nature rather than nurture. The available evidence indicates that infants are sensitive to a number of sound features that are fundamental to music across cultures. Their discrimination of pitch and timing differences and their perception of equivalence classes are similar, in many respects, to those of listeners who have had many years of exposure to music. Whether these perceptual skills are unique to human listeners is not known. What is unique is the intense human interest in music, which is evident from the early days of life. Also unique is the importance of music in social contexts. Current ideas about musical timing and interpersonal synchrony are considered here, along with proposals for future research.

Before considering the musical abilities of infants, it is useful to reflect on some parallels between music and language, especially those that may be relevant to the course of development. Music is rule-governed, as is language. Each musical style uses a relatively small set of rules to generate a potentially infinite variety of compositions, or pieces. Music also embodies the property of recursion, which may be the most important distinction between language and non-human systems of communication[1]. Just as a sentence can be lengthened indefinitely by the insertion of words or other sentences, so a musical piece can be altered by the insertion of phrases or other musical units. Musical pieces can be transformed not only in their horizontal, or melodic, dimension but also in their vertical, or harmonic, dimension, as in the case of multi-part singing or instrumental accompaniment. Despite considerable transformation (*e.g.*, jazz renditions of pop tunes), the identity of familiar pieces is often preserved, which implies that music has an abstract core or 'gist' that underlies its surface form. In the absence of disability, commonplace musical competence (such as recognizing and producing tunes) is acquired effortlessly, as is conventional linguistic competence. Training and deliberate practice may be required for skilled performances of music, but they are also required for skilled recitation and oration. Nevertheless, toddlers commonly invent songs before they can reproduce conventional songs[2]. Similarly, school-age children create songs and chants (such as "Eenie-meenie-miney-mo") that share a number of features across cultures, including repetition, rhythmic patterning, rhyme and alliteration[3]. (For other perspectives on music and language, especially as they relate to adults, see the accompanying review by Patel[4] in this issue and ref. 5)

Music parts company with language when it comes to meaning. Although both music and language show duality of patterning[6] (discrete, meaningless elements are combined to produce meaningful structures), the resulting musical pieces are not meaningful in the same way that verbal utterances are. In other words, music lacks 'semanticity'. Because of its non-referential nature and its lack of obvious utility, music is typically viewed by scientists as an interesting but evolutionarily irrelevant artifact[7]. This view, however, ignores its historical and cross-cultural[8] ubiquity, its continued importance in everyday life[9,10] and its impact on the emotions of listeners and performers[11–13].

Department of Psychology, University of Toronto at Mississauga, Mississauga, Ontario L5L 1C6, Canada. Correspondence should be addressed to S.E.T. (sandra.trehub@utoronto.ca).

Perceptual perspectives

The music perception skills of prelinguistic infants are surprisingly similar to those of listeners who have had years of informal exposure to music. From the age of about 6 months, the ability to perceive specific changes in a melody can be assessed by providing the infant with a reward (such as a glimpse of a mechanical toy) for responding to the change (by turning toward a laterally displaced loudspeaker)[14]. By repeating the melody in transposition (that is, at different pitch levels) or at a different tempo (faster or slower), infants must solve the discrimination task on the basis of relative rather than absolute pitch or timing cues. If infants respond more consistently to altered melodies than to functionally equivalent (transposed) melodies, that confirms their detection of the change in question. It also implies that infants remember the relevant features of the original melody or tone sequence. Conditioning procedures such as these have revealed that infants' resolution of pitch[15] and timing[16] enables them to detect the smallest differences that are musically meaningful in any culture.

Of particular interest for the present review are adult–infant parallels in music processing. For example, infants recognize the invariance of melodies across shifts in pitch level (transpositions) and tempo[17]. For adults, as for infants, these changes are detectable, but they are irrelevant to the identity of musical pieces. Equally intriguing is the finding that infants are more precise in perceiving diatonic melodies—those conforming to keys of major or minor scales—than melodies that violate the conventions of known musics[18]. In the context of non-diatonic melodies, for example, infants detect changes in relative pitch only when such changes alter the melodic contour, or the pattern of directional changes in pitch[17]. Melodic contour is a particularly salient dimension of novel melodies for adults as well as infants. For diatonic melodies, infants detect pitch changes of a semitone or less, even when the melodic contour is unchanged[19,20].

Infants' perception of intervals (that is, two simultaneous or sequential tones) considered consonant or pleasant-sounding, such as

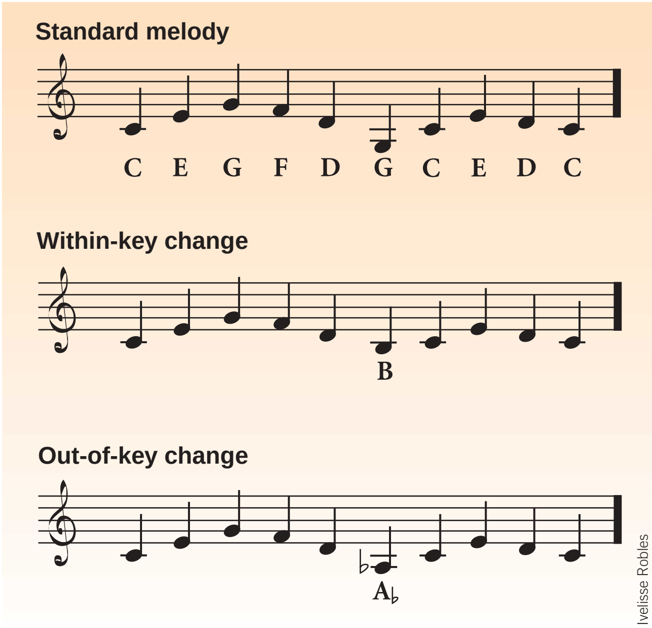

Figure 1. Standard and comparison melodies presented in C-major. For the within-key change, the sixth note is shifted four semitones upward, but the change preserves the diatonic and harmonic framework. For the out-of-key change, the sixth note is shifted one semitone upward, which violates the diatonic framework.

the 'perfect fifth' (pitch distance of seven semitones, such as C→G) or 'perfect fourth' (pitch distance of five semitones, such as C→F), is more precise than is their perception of dissonant intervals such as the tritone (pitch distance of six semitones, such as C→F#)[21]. Incidentally, the fundamental frequencies (pitches) of component tones of the perfect-fifth and perfect-fourth intervals are related by small-integer ratios (3:2 and 4:3, respectively), whereas dissonant intervals such as the tritone (45:32) are related by large-integer ratios. When the presentation of contrasting auditory patterns is linked to infants' visual fixation on either of two loudspeakers (with each pattern delivered from a specific loudspeaker), 2- and 6-month-old infants listen longer to sequences of consonant intervals than to sequences of dissonant intervals[22,23]. In a similar vein, 4-month-old infants are content to listen to unfamiliar folk melodies, but they show signs of distress (fussing, squirming, gaze aversion) for versions in which dissonant intervals replace some of the consonant intervals[24]. The aforementioned similarities between infants and adults are consistent with processing predispositions for aspects of musical structure[17,25] and correspond to features that are common across musical cultures[26]. It is reasonable to conclude, then, that the rudiments of music listening are gifts of nature rather than products of culture.

In principle, these parallels between infants and adults could arise from prenatal or postnatal exposure to ambient music[27]. Infants are sensitive to regularities in auditory input[28,29], and they show long-term recognition of musical pieces[30], but there is no indication that exposure enhances their sensitivity to important aspects of musical structure, either in infancy or in the preschool period. In fact, sensitivity to culture-specific details of tonal and harmonic structure seems to emerge between 5 and 7 years of age[31,32]. Although musical training can accelerate the course of culture-specific attunement, the process is anything but rapid. In the long run, incidental exposure is sufficient to generate music perception skills that are similar to those of trained musicians[33].

Usually, but not always, exposure to music leads to greater differentiation in the processing of musical sequences. Sometimes listeners with years of exposure to music fail to notice distinctions that are apparent to musical novices, just as adults fail to notice non-native phonetic distinctions (such as *l* and *r* for native speakers of Japanese; *b* and *v* in some dialects of Spanish) that are apparent to prelinguistic infants[34]. For example, musically untrained adults are typically unable to detect a large (four-semitone) pitch change (**Fig. 1**) in a melody if the change preserves the musical meaning (same key and harmonic implications; **Supplementary Audio 1** online), but they readily detect a subtle (one-semitone) pitch change that alters the meaning (key violation; **Supplementary Audio 2**). By contrast, infants detect both changes equally well[35], which implies that culture-specific exposure is relevant to adults but not to infants in this instance.

Infants also detect mistunings, or subtle pitch changes, to simple melodies based on Western or Javanese scales, but adults perform at chance levels on the unfamiliar Javanese melodies[36]. Both infants and adults detect small pitch changes (less than a semitone) in the context of the major scale, which embodies unequal scale steps, and they fail to detect comparable changes in the context of an invented scale with equal steps[20]. They differ, however, in the ability to detect a similar pitch change in the context of an invented scale with unequal steps: infants have this ability and adults do not[20]. Adults' performance in this instance is affected by musical exposure and familiarity, but infants' performance is related to universal constraints on scale structure—unequal scale steps in particular[37]. The results of several studies imply that infants are universalists in the sense that they are perceptually equipped for the music of any culture[17,25]. The cultural relativism and skepticism about musical universals that prevailed for several years among ethnomusicologists is undergoing considerable change[38,39]. Ultimately, musical similarities across cultures are likely to outstrip similarities across languages, especially if the focus is on everyday music rather than art music, and musical functions rather than styles of performance.

In what sense is music unique?

Music must involve uniquely human abilities of some kind, but it is unclear whether perceptual abilities are part of that uniqueness. One notable aspect of music is its relational organization, which makes the perception of invariance across pitch level and tempo an interesting candidate for comparisons across species. If non-human listeners are able to detect invariant aspects of musical sequences, then perceptual factors may not contribute to the uniqueness of music. Starlings generalize conditioned responses to tone sequences across variations in tempo[40], and white-throated sparrows identify conspecifics by relative pitch cues[41]. For avian species, however, relational pitch processing is secondary to absolute pitch processing[42].

Of greater potential interest are our primate relatives[27], who are thought to focus on absolute rather than relative features of auditory patterns[43]. Wright and his associates[44] report, however, that rhesus monkeys can recognize transposed tunes, but only under very restrictive circumstances. First, the monkeys recognized transpositions of children's songs like "Old McDonald Had a Farm" and other diatonic melodies, but they did not recognize transpositions of non-diatonic melodies. Infants and adults have similar limitations, as reflected in their tendency to confuse transpositions of non-diatonic melodies with renditions that preserve the pitch contour but not the intervals of the original[19]. Second, the monkeys recognized transpositions of one or two octaves, but not transpositions of 0.5 and 1.5 octaves. Melodies separated by an octave are

Three-month old triplets enjoying an informal performance of maternal singing.

related by a frequency ratio of 2:1, and are in the same key. Those separated by half an octave (six semitones) stand in a 45:32 ratio, and their keys are musically unrelated, or distant. Infants and adults notice similarities and differences between melodies most readily when the keys are closely related (by small-integer ratios), but they have difficulty comparing melodies in distantly related keys (involving large-integer ratios)[45].

In an accompanying review in this issue, Hauser and McDermott[27] raise the possibility that the monkeys' performance could have been influenced by incidental exposure to television in the laboratory environment. If very limited exposure to music, on television or otherwise, results in sensitivity to tonal structure in monkeys or humans, then innate learning preferences[46] would be implicated. The critical question, in my view, is whether non-human primates would be able to recognize melodies transposed by a perfect fifth (3:2)—an interval that is fundamental to the music of many cultures[47]. That achievement would provide clearer evidence of sensitivity to musically relevant pitch patterns.

Social perspectives

If human perceptual skills are not at the root of the uniqueness of music, what other factors might be implicated? Those related to social interaction are promising candidates. Humans are intensely social creatures, and music is largely a social endeavor. Even solitary music listening, which emerged with the advent of recording technology, evokes feelings that are embedded in a social context[9].

An examination of mother–infant interactions provides a glimpse into our social and musical beginnings. Throughout the world, mothers provide musical input of various kinds to their prelinguistic infants. They speak in melodious tones to infants who cannot understand what they say[48]. They also sing a great deal, using a special genre of music with common features across cultures, such as simple pitch contours, repetition and narrow pitch range[10]. For example, naive listeners can distinguish foreign lullabies from non-lullabies matched on culture of origin and tempo[49].

In general, the maternal repertoire of songs for infants is limited to a handful of play songs or lullabies that are performed in an expressive and highly ritualized manner[10,50] (see **Supplementary Video 1** online). From the neonatal period, infants prefer acoustic renditions of a song in the maternal style (performances from mothers of other infants) to non-maternal renditions of the same song by the same singer[51,52]. Moreover, they are entranced by performances in which they can both see and hear the singer, as reflected in extended periods of focused attention and reduced body movement in the infant[53]. It may be tempting to attribute these preferences to prenatal exposure, but such exposure should generate preferences for typical (non-maternal) styles of singing rather than performances in the maternal style. Moreover, hearing newborns whose deaf parents communicate by means of sign language show comparable preferences for singing in the maternal style, despite their lack of relevant experience[51]. Infants' interest in maternal speech, while considerable[48], does not match their interest in maternal singing[53]. Indeed, the music in speech seems to underlie its attractiveness to prelinguistic infants[48]. There are visual, non-vocal analogs of infants' attraction to maternal speech and singing: hearing as well as deaf infants prefer the gestural patterns of infant-directed sign language to those of conventional sign language[54,55]. Emotional expressiveness seems to be the common factor in these across-modality preferences.

Social regulation is clearly at the heart of music for infants and young children, and may be an equally important part of musical experiences throughout life. Passive listening and private musical activities figure more prominently in current times than they did in ancient times. For our pre-industrial forebears, as for people in some communities today, active music-making was centrally involved in ceremonies, rituals and daily life[8,56]. The regular pulse and discernible rhythms of music facilitate the coordination of movements and emotions among people in small or large groups[11]. According to historian William McNeill[57], aspects of group bonding that arose from community dancing (to music) in earlier eras are now achieved by the coordinated movements of military drills. Although the original function of such drills (*i.e.*, battle formation) is now obsolete, coordinated drills still result in invaluable camaraderie or *esprit de corps*. Comparable physical and emotional synchrony is often attained by highly engaged audiences at rock concerts, soccer matches and protest rallies.

Precise coordination of movements among conspecifics is evident in a number of species, but it is restricted to a narrow range of tempi. What is lacking is the distinctly human ability to synchronize with an external timekeeper such as an instrument, metronome or dancing partner[58] Benzon[11] pushes the case for synchrony much further, arguing for music's uniqueness on the basis of its activation of widespread neural networks and its coordination of the temporal flow of neural activity, both within and across active participants in music. He focuses on phylogenetically old structures like the reticular formation, with its extensive afferent and efferent connections,

Seven-month-old triplets awaiting their turn in an experiment on melody discrimination.

and on the limbic system, which is involved in emotion and social interaction. He contends that together with coordinated musical behaviors like playing, singing and movement, coordinated neural activities during musical engagement generate feelings of 'flow'[59] (intense engagement involving some loss of time or place), heightened pleasure or altered states of consciousness.

Whether the pursuit of music and the pleasure we derive from it are linked to the synchronous neural states described by Benzon[11], to oxytocin-mediated dissolution and restructuring of interpersonal boundaries[60], to the neurophysiological mirroring of tonal flow[61] or to other mechanisms remains to be determined. Much less controversial are the commonplace interpersonal and social consequences of musical activities. An important part of the uniqueness of music may stem from our biologically based social nature, which motivated the creation of elaborate systems of music and continues to motivate musical activity in the present, as it did in the distant past. From the earliest days of life, infants are keenly responsive to social stimuli—human faces as well as voices—especially when they reflect positive emotional states[62]. For infants, the power of music may arise from its social nature and its link to positive emotions.

Some unanswered questions

The available evidence provides a rough outline of the initial state of the human music listener. As additional evidence accumulates, the list of adult–infant parallels is likely to grow. Progress by ethnomusicologists in identifying musical universals would facilitate the corresponding search for universals of music processing, and studies with non-human primates should reveal whether any of the processing universals are unique to human listeners.

Music is not communicative in the sense of sharing information. Instead, it is concerned with sharing feelings and experiences and the regulation of social behavior. In identifying universals in music that are unrelated to sound or style, Nettl[39] notes that music is used to alter the consciousness of individuals and the ambiance of groups. Human and non-human comparisons are valuable in some respects, but their importance must be qualified by the links between music and the human experience of well-being[8]. One important challenge of future research is to gain greater insight into the motivational basis of music making and music listening. In terms of its prevalence and impact, music seems more like a necessity than the pleasure cocktail envisioned by Pinker[7]. We must also consider the fact that instrumental music is widely distributed but not as universal as vocal music is. Does vocal music have primacy for infant listeners, and does the impact of instrumental music stem from its connections to vocal music?

Benzon's[11] challenge regarding behavioral and neurophysiological aspects of temporal synchrony in music making and listening should be pursued with participants of different ages. In musical interactions between mothers and infants, do infants follow their mothers' lead, or do mothers synchronize with their infants' natural rhythms? What are the behavioral and neurophysiological consequences of musical interactions between mothers and infants? At what age and in what ways does culture-specific experience influence emotional ties among those who share musical experiences?

Congenitally deaf children with cochlear implants pose other interesting challenges because their prostheses provide poor pitch resolution but good temporal resolution. Musical pleasure and resulting interpersonal coordination in this population would confirm the centrality of timing to the experience of music. Musical pleasure in these deaf children would also raise doubts about the proposal that congenital amusia—the inability to appreciate music in the absence of detectable brain damage—stems from limitations in fine-grained pitch discrimination[63].

Finally, we need to explore whether part of the allure of music stems from its indeterminate meaning. Music's lack of referential meaning may allow listeners of all ages to engage in some form of social or pretend play, projecting imaginative fantasies onto the musical forms that they hear, and forging interpersonal bonds in the process.

Note: Supplementary information is available on the Nature Neuroscience website.

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