Chapter 4
Music Acquisition and Effects of Musical Experience

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4.1 Introduction

Rather little is known about how children acquire musical knowledge. However, everyday exposure to the music of one's culture does lead to implicit knowledge about its pitch and rhythmic structure, just as exposure to a particular language leads to implicit knowledge about its structure. While all children attend school with the goal of becoming literate, some children engage in formal music training whereas others do not. Thus music offers the opportunity to compare the effects of a wide range of experiences (Trehub and Trainor 1998).

This chapter examines the effects of musical experience on the development of three aspects of musical structure: pitch organization, rhythm, and emotional expression. For each aspect of musical structure, this chapter (1) selectively overviews what is known about how it develops, in cross-cultural perspective where possible; (2) examines how adult musicians and nonmusicians differ (the end-state of development); and (3) reviews the evidence for the role of experience in causing these differences. Finally, the effects of musical experience on other cognitive domains are considered in relation to whether it has general benefits across many domains or specific benefits in a few domains such as reading or visual–spatial skills, and what the mechanisms might be for such transfer.

Engaging infants and young children in music appears to be a cross-cultural universal, and it has been suggested that music, like language, is a species-specific behavior important for complex human social interaction (e.g., Trehub 2000, 2003). As recorded music becomes easier to produce and distribute, the nature of human musical engagement is changing, and the speed at which new musical compositions and styles are evolving appears to be increasing. In this context, it is important to consider the nature of musical development and the effects of different kinds of musical experience.

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4.2 Pitch Organization

4.2.1 Development of Pitch Organization: Musical Enculturation

Musical pitch structure includes several different aspects that, although they interact, have different developmental trajectories. The most basic level is that of *individual musical tones*, which typically have energy at a fundamental frequency and integer multiples of that frequency, called harmonics (e.g., for a fundamental frequency of 100 Hz, there would also be energy at 200, 300, 400, … Hz). The auditory system analyzes this spectrotemporal information and extracts a pitch percept that normally corresponds to the fundamental frequency. Individual tones are concatenated into sequences to form *melodic structures* and they are also combined simultaneously to form chords which are put into sequences to form *harmonic structures*. The details and indeed the presence of melodic and harmonic structure vary substantially between musical systems, but some basic principles appear to be close to universal, such as (1) to give prominence to pitch intervals (the pitch distance between tones) whose fundamental frequencies stand in small integer ratios and sound consonant; (2) to treat tones an octave apart as functionally equivalent (e.g., all the Cs or all the Ds on the piano); (3) to divide the octave into a small number of notes (usually between five and nine) that serve as discrete pitches for musical composition; (4) to have two or more interval sizes in scales so that the notes of the scale can be differentiated and take on different functions; and (5) to favor relative over absolute pitch representations, allowing melodies to be recognized across different starting pitches.

Because so little is known about children's acquisition of non-Western musical systems, this section on pitch organization focuses on the acquisition of Western tonal music. It will be for future research to determine whether the principles by which Western musical knowledge is acquired apply universally. The first subsection examines basic pitch processing and enculturation to Western melodic and harmonic structure under conditions of normal everyday exposure. Later subsections examine the effects of specific musical experience and training on musical acquisition.

Very young infants have some ability to distinguish pure tones with different frequencies. For example, during the last month before birth, the fetus responds to a change in pitch of roughly an octave (Hepper and Shahidullah 1994; Lecanuet et al. 2000) and neonates show event-related potential (ERP) responses in electroencephalograph (EEG) recordings to a 10% change in the pitch of a 1,000-Hz pure tone (Leppänen et al. 1997, 2004; Čeponiené et al. 2002). Pitch discrimination improves rapidly over the months after birth, although it does not reach adult levels until 8–10 years of age (Werner and Marean 1996). However, the ability to discriminate the smallest meaningful pitch difference in Western music, the semitone (6%), is present at least as early as 2 months of age (Werner and Marean 1996; He et al. 2009).

Musical tones are typically complex, containing harmonics that the auditory system integrates into a percept of a single tone with a particular timbre. The ability to extract pitch from complex tones can be measured by the ability to perceive the pitch of the missing fundamental. If all energy is removed at the fundamental frequency, the pitch of a complex tone does not change (although the timbre does) because the pitch is implied by the spectrotemporal pattern across the harmonics; hence, the phenomenon is referred to as perceiving the pitch of the missing fundamental. Behavioral data indicate that 7-month-old infants integrate the harmonics of complex tones into a single pitch percept (Clarkson and Clifton 1995), and recent EEG data indicate that cortical representations for the pitch of the missing fundamental are present at 4 months of age (He and Trainor 2009). Thus, young infants have the basic pitch perception capabilities to allow musical processing.

Indeed, 2-month-old infants are able to recognize familiar melodies (Plantinga and Trainor 2009) and even neonates can segregate tones in a sequence into those with high pitch and those with low pitch (Winkler et al. 2003). Further, infants are sensitive to a number of melodic structural features that are similar across musical systems. First, they more readily encode scales with unequal interval sizes than scales with only one size of interval (Trehub et al. 1999). Second, infants find it easier to process certain musical intervals than others. Specifically, like adults, they are better able to process consonant than dissonant intervals. Intervals that sound consonant (pleasant to adults) consist of tones for which fundamental frequencies stand in small integer ratios, such as 2:1 (octave) and 3:2 (perfect fifth) whereas intervals with larger integer ratios, such as 15:8 (major seventh) or 45:32 (tritone) sound dissonant (rough or unpleasant). Given a set of consonant-interval standards, infants readily detect occasional dissonant comparison intervals, but they are unable to do the reverse discrimination (i.e., detect occasional consonant intervals among a set of dissonant intervals; Trainor 1997). Similarly, Schellenberg and Trainor (1996) found that infants more readily detect a change in a perfect fifth that creates a dissonant interval than a change that creates a different consonant interval, indicating that consonant intervals sound similar to infants. Further, infants as young as 2 months of age prefer to listen to consonant intervals compared to dissonant intervals (Trainor et al. 2002a). The superior processing of consonant intervals extends to melodic processing. Infants are better able to detect changes to melodies with prominent consonant intervals compared to melodies with prominent dissonant intervals (Trainor and Trehub 1993).

A third melodic structural feature to which infants are sensitive is transpositional invariance, reflecting the fact that melodies maintain their identity when played at higher or lower pitch levels as long as the relative pitch distances between tones remain constant. Although infants may process absolute pitch under some circumstances (Saffran and Griepentrog 2001; Volkova et al. 2006), they appear to favor relative pitch representations, as do most adults (Trehub et al. 1984; Plantinga and Trainor 2005, 2008). One indication that absolute pitch information for isolated tones fades rapidly in adults who do not possess absolute pitch is that the more interference or distractor tones with random pitches that are placed between two target tones, the worse adults are at detecting whether or not the target tones have the same or different pitches (Ross et al. 2004). Plantinga and Trainor (2008) showed that the same is true for infants. On the other hand, when a melody is transposed up or down in pitch, the absolute pitch of every note in the melody changes. The ability to recognize a melody in transposition therefore relies on processing the distances between tones of the melody, that is, relative pitch. Infants can detect a change to one note of a melody, even when the comparison melodies are presented in transposition to different pitch levels (e.g., Trehub et al. 1984; Trainor and Trehub 1992a), suggesting good relative pitch processing early in development. Long-term memory representations also appear to be primarily in terms of relative pitch in infants. After being exposed to a melody for a week, infants prefer to listen to an unfamiliar melody, and this preference is unaffected by whether the familiarized melody is presented at the pitch level heard during familiarization or at a new and substantially different pitch level (up or down a perfect fifth or tritone), indicating that long-term memory representations are coded in terms of relative pitch (Plantinga and Trainor 2005).

Despite these precocious abilities, however, it takes some time for young infants to become enculturated to Western major scale structure, despite daily exposure during everyday activities. Lynch et al. (1990) showed that Western infants were equally able to detect changes to unfamiliar Balanese scales and Western scales, although their parents performed much better with the Western scales. Trainor and Trehub (1992a) showed that although Western adults find it much easier to detect a change to an unfamiliar melody when the changed note deviates from notes of the major scale (or key) compared to a change that remains within the notes of the scale, infants are able to detect both types of changes, actually outperforming adults in some conditions involving within-key changes. Out-of-key notes are readily detected by adults because their implicit knowledge of Western scale structure makes such notes sound wrong, whereas within-key notes do not violate Western scale structure. Thus infants' relatively good performance on within-key changes actually indicates a lack of knowledge about Western scale structure. The average age at which scale knowledge, or key membership, is solidified remains unknown, but it is certainly present by 4 or 5 years of age (Trehub et al. 1986; Trainor 2005; Corrigall and Trainor 2009).

Cortical representations for melodies remain immature for a much longer period than representations for individual tones. The simultaneous activation of groups of neurons in auditory cortex in response to the presentation of a sound can be measured at the surface of the scalp through the electrical fields that are generated. Following the direction of axons between layers in auditory areas located around the Sylvian fissure, such neural events appear as dipolar patterns on the scalp, with anterior negativities concurrent with posterior positivities, or vice versa. The stages of sound processing can be tracked through a series of frontally positive and negative components in the ERP over time (e.g., see Luck 2005). During the first months after birth, ERP responses to sound are dominated by slow waves that are not present in adult responses (for a review, see Trainor 2007). In adults, cortical memory traces for sound can be examined by measuring responses to occasional changes (deviants) in a repeating sound (standard), or changes in the category of a stream of sounds. Such occasional deviants elicit a negative ERP component not present in the response to standards, termed a mismatch negativity (MMN; for reviews, see Picton et al. 2000; Näätänen et al. 2007). The MMN typically peaks between 130 and 250 ms after the onset of the change depending on stimulus complexity, and appears at the scalp as a negativity at anterior sites, concurrently with a positivity at posterior sites, consistent with a primary generator of the electrical field in secondary auditory cortex. Cortical memory traces for infants are somewhat different. During the first couple of months after birth, no MMN is seen, but a simple change in the pitch of a repeating musical tone elicits an increase in a frontally positive slow wave. The amplitude of this wave decreases with age, and an MMN resembling that of adults emerges around 3 months of age (He et al. 2007, 2009). Adults also show MMN responses to more complex stimuli such as melodies, even when those melodies are presented in transposition from repetition to repetition (e.g., Fujioka et al. 2004). However, in infants as old as 6 months, changes to melodies in transposition produce an increase in a slow frontally positive wave rather than the adult frontally negative responses (Tew et al. 2009). In sum, despite the fact that young infants recognize melodies, cortical processing remains immature and it takes considerable musical exposure to become acculturated to the musical scales in the environment.

Elaborate harmonic structure is relatively rare across the world's musical pitch systems, and from this perspective, it is interesting that sensitivity to harmony is typically rather late in developing, not reaching adult levels until at least 12 years of age (Costa-Giomi 2003). However, the perceptual distinction between consonance and dissonance is likely a necessary precursor of sensitivity to harmony because chords are built primarily on consonant relations between the notes comprising them. For example, the two most prominent chords in a key, the tonic chord, which is based on the first note of the scale, and the dominant chord, which is based on the fifth note of the scale, involve simultaneous tones that form consonant intervals (see Tramo et al. 2001). Infants prefer to listen to consonant compared to dissonant intervals (Trainor and Heinmiller 1998; Zentner and Kagan 1998; Trainor et al. 2002a). Further, this preference for consonance may be innate as it is present even in hearing newborns of deaf parents (Masataka 2006). Using EEG measures, Koelsch et al. (2003) showed that when the final chord in a sequence (i.e., in a chord progression) contains a note that deviates from the key of that sequence, a brain response to this unexpected chord is elicited from children as young as 5 years of age. Similarly, children as young as 6 years were found to be faster to make judgments about the last chord in a progression of chords (e.g., they judged which of two vowels was sung on the last chord) when the final chord was a tonic chord compared to when it was a subdominant chord (based on the fourth note of the scale; Schellenberg et al. 2005). Although all of the notes of the tonic and subdominant chords are contained within the key, sequences ending in a subdominant chord sound incomplete to a Western-enculturated listener. In a recent study, Corrigall and Trainor (2009) found that children as young as 4 years rated sequences ending in a tonic chord as sounding "good" significantly more often than sequences ending in a subdominant chord. Thus some sensitivity to harmonic progressions is present as young a 4 years of age.

In Western music, melodic and harmonic aspects of pitch structure interact, such that a melody presented alone "implies" the harmony that could accompany it. Trainor and Trehub (1994) showed that adults and 7-year-olds, but not 5-year-olds, process melodies according to their implied harmony. Specifically, a change in one note of a melody that remained within the key of the melody, but implied a different harmony from the original melody, was readily detected by 7-year-olds and adults, but not by 5-year-olds. On the other hand, all three groups were sensitive to scale structure (keys) as they all readily detected changes that deviated from the established key. These results are consistent with those from probe tone studies wherein children rate how well a tone fits into a preceding context (e.g., Krumhansl and Keil 1982; Speer and Meeks 1985; Cuddy and Badertscher 1987).

In sum, young infants are able to derive pitch from harmonics, discriminate musical pitches, and differentiate consonant and dissonant intervals. On the other hand, it takes considerable musical exposure and maturation before sensitivity to culture-specific scale and harmonic structure emerges. It is noteworthy that none of these developments requires formal musical training or explicit knowledge of musical structure, but rather they arise through everyday exposure to music.

4.2.2 Differences Between Adult Musicians and Nonmusicians in Musical Pitch Processing

By the time they reach adulthood, musicians have spent many years practicing their instrument, often for several hours each day, and this experience typically began at an early age. Further, although music is based in the auditory modality, learning a musical instrument provides intense multisensory experience that integrates motor processing with auditory, visual, tactile, and proprioceptive input. To examine the effects of this experience, a number of studies have compared auditory and multisensory processing in adult musicians and nonmusicians to study the effects of experience. Although innate factors influencing the decision to engage in musical training at a young age often cannot be ruled out, these studies provide a good starting point for examining the effects of musical experience.

Magnetic resonance imaging (MRI) studies indicate structural brain differences between musicians and nonmusicians (see Bermudez et al. 2008; Schlaug 2009). For example, Schneider et al. (2002) found that gray matter in auditory cortex is enlarged in musicians compared to nonmusicians, and that the degree of enlargement is correlated with musical skill. Structural differences are not limited to the auditory cortex. Compared to nonmusicians, musicians have more gray matter in Broca's area (Sluming et al. 2002), cerebellum (Hutchinson et al. 2003), and motor areas (Gaser and Schlaug 2003; Bangert and Schlaug 2006). Using a new measure of cortical thickness, Bermudez et al. (2008) found that the cortex of musicians is thicker than that of nonmusicians in secondary auditory cortical areas, particularly on the right, as well as in dorsolateral frontal cortex, an area associated with executive functions and working memory. Functional magnetic resonance imaging (fMRI) studies also suggest the involvement of a wide network of areas (e.g., Koelsch and Siebel 2005). The involvement of frontal areas likely reflects the great demands that musical performance places on the retention, monitoring, and retrieval of sound patterns.

While MRI studies give detailed information about where processing takes place in the brain, the stages of sound processing can be tracked with EEG and magnetoencephalographic (MEG) recordings, which monitor changes in electrical and magnetic fields associated with the synchronous depolarization and firing of groups of neurons. The presentation of a sound triggers a series of positive and negative field deflections at the surface of the head, each reflecting activity at a particular time from one or more brain regions. Many ERP components have been found to be larger in amplitude and/or earlier in musicians compared to nonmusicians (see Näätänen et al. 2007; Trainor and Zatorre 2009 for reviews). For example, preattentive middle-latency responses originating in primary auditory cortex are enhanced in musicians (Schneider et al. 2002; Shahin et al. 2004). Similarly, several preattentive components originating in secondary auditory cortical areas are larger and/or earlier in musicians than in nonmusicians (e.g., N1b at 100 ms after stimulus onset, Pantev et al. 1998; N1c around 170 ms, P2 around 200 ms, Shahin et al. 2005; Kuriki et al. 2006). These differences reflect either an increased number of neurons involved in processing musical sounds or an increased synchronization across neurons in musicians compared to nonmusicians.

Another preattentive ERP component, the MMN, is also larger in musicians than in nonmusicians. MMN is activated when an unexpected sound is inserted into a stream of similar sounds. It is thought to reflect the updating of sensory memory (e.g., Picton et al. 2000; Näätänen et al. 2007). A pitch change in a short melody that is repeated in transposition from trial to trial elicits an MMN that is larger in musicians than in nonmusicians (Fujioka et al. 2004). Likewise, when two melodies are presented at the same time in a polyphonic texture, separate memory traces are formed for each melody, and the MMN elicited by changes in each melody is larger in musicians than in nonmusicians (Fujioka et al. 2005). For harmonic processing, Koelsch and his colleagues have shown that chords that are unexpected in the context elicit an early right anterior negativity that again is larger in musicians than in nonmusicians (Koelsch et al. 2002). Finally, ERP components that involve attentional processing are also larger in musicians compared to nonmusicians, as evidenced by a larger P3a component, reflecting attentional capture of sounds in an unattended stream (e.g., Fujioka et al. 2004, 2005); a larger P3b component, reflecting conscious decision making about a sound (e.g., Trainor et al. 1999); and larger gamma band responses, reflecting networks for focused attention (Shahin et al. 2008).

The previous two paragraphs outline substantial evidence for structural and functional differences between musicians and nonmusicians. But just how different are they? Do musicians and nonmusicians differ simply in the degree of cortical network activation or do they exhibit qualitatively different processing? The answer depends on the perspective taken. Although brain regions associated with musical processing are larger in musicians, and although ERP responses to musical sounds and violations of musical structure are generally larger and earlier in musicians, the particular brain areas involved and the particular ERP components generated are the same in the two groups. Thus, one interpretation is that all people (in the absence of congenital or acquired amusia) are musical, and training simply enhances musical processes. Indeed, this was the conclusion of Trainor et al. (2002b) when they found preattentive brain responses in nonmusicians in response to out-of-key notes in a melody, even though the melody was transposed to a different key from repetition to repetition. Interestingly, some behavioral studies have led to similar conclusions. Bigand, Tillmann, and colleagues have shown that when implicit tasks are used so that participants do not have to make a musical judgment directly, nonmusicians are sensitive to key structure and harmonic structure (Bigand and Poulin-Charronnat 2006). For example, when asked to judge the tuning (e.g., Bharucha and Stoeckig 1986, 1987), consonance (Bigand and Pineau 1997; Tillmann et al. 1998; Bigand et al. 1999) or timbre (Tillmann et al. 2006) of the last chord in a sequence, nonmusicians as well as musicians are faster when this final chord is expected, given the preceding context, than when it is not expected.

Perhaps musician/nonmusician differences can best be viewed as follows. Through everyday listening experience, nonmusicians and musicians are exposed to similar culture-specific musical pitch structures, and both groups become sensitive to these structures, likely through the operation of automatic statistical learning mechanisms. On the other hand, with formal training, compared to nonmusicians, musicians amass more experience with music than nonmusicians, they learn complex motor-auditory interactions in order to play their instruments, and they typically acquire explicit as well as implicit knowledge about musical structure. Thus they build larger and faster networks than nonmusicians for processing musical structure.

The final question to consider in this section is whether the differences seen in musical processing between musician and nonmusician adults reflect experience or whether those who became musicians engaged in extensive musical training from a young age because they were genetically predisposed to process music easily. This question is very difficult to answer. However, a couple of lines of evidence suggest that musician/nonmusician differences in adulthood are mediated at least to some extent by experience. First, within musician groups, the size of the N1 response correlates negatively with the age of onset of music lessons (Pantev et al. 1998), as does the size of the P3 response (Trainor et al. 1999). Second, ERP enhancements are most pronounced for tones of the timbre of the musical instrument of practice. For example, pianists show larger N1 responses to piano tones than to trumpet tones, and trumpet players show the reverse (Pantev et al. 2001). Third, many of the ERP components that are larger in musicians compared to nonmusician adults remain somewhat neuroplastic and can be modified in amplitude or latency through laboratory training in adults. For example, Bosnyak et al. (2004) trained adult nonmusicians in frequency discrimination and found that behavioral improvements in discrimination were accompanied by increases in P2 amplitude that were specific to the trained frequency. Further, multisensory training can effect larger changes in auditory areas than auditory training alone. Lappe et al. (2008) trained one group of nonmusicians to play simple note sequences on the piano. A second group heard the same sequences and made judgments about them without learning to play them. After this training, the group that experienced the multisensory training showed larger MMN responses to wrong notes in similar sequences.

In sum, the evidence suggests that adult musician/nonmusician differences reflect, to a considerable extent, different musical experiences in childhood. In the next section, we consider studies with children that have tested the role of experience more directly.

4.2.3 Effects of Formal Musical Training on Children's Perception of Pitch Structure

Surprisingly, little scientific research has examined the effects of musical training on musical development in infants and young children. Much of the existing literature concerns absolute pitch training, which is generally not considered a core musical ability. Here, we focus on the effects of formal musical training on enculturation to musical pitch structure, with an emphasis on the development of harmonic sensitivity.

A few studies have shown differences in brain responses in young children engaging in music lessons compared to children not taking lessons. Interestingly, regardless of musical training, the auditory cortex has a very long developmental trajectory. ERP responses from auditory cortex to isolated musical tones continue to mature well into the teenage years (Ponton et al. 2000; Trainor et al. 2003; Shahin et al. 2004). Specifically, ERP components at around 50 ms (P1), 100 ms (N1), and 200 ms (P2) after sound onset increase in amplitude and decrease in latency until about 10 years of age, and then decrease in amplitude until adult levels are reached at around 18 years of age. Early musical training affects this trajectory. Shahin et al. (2004) found that 4- and 5-year-old children taking music lessons showed ERP responses that were similar to those of children 2–3 years older who were not taking music lessons. Further, the responses were consistent with the effects of musical training being specific to the timbre of the musical tones of the instrument of practice. Shahin et al. (2008) analyzed the ERP data of Shahin et al. (2004) in the frequency domain, specifically looking at responses in the gamma band range (40–100 Hz). Induced or non–phased-locked gamma band responses are particularly interesting because they have been linked to top-down processing or executive functions relating to attention and memory. The results showed that induced gamma band responses were present only in the group engaging in music lessons, and in that group, only after a year of music lessons. These data converge with those of Fujioka et al. (2006), who used MEG to show that in children of this age, an ERP component (the N2), which is related to auditory attention and memory processes, matures differently over the course of a year in children taking music lessons compared to children not taking music lessons. In sum, music lessons appear to affect basic auditory processing of isolated musical tones.

One study has examined the effects of musical training on brain responses to violations of Western harmonic structure. Jentschke et al. (2005) compared 11-year-old children in the Saint Thomas Boys Choir in Leipzig with children not engaging in formal musical training who were matched for IQ and parents' education level. They measured ERP responses to the final chord in a sequence, specifically examining an early right anterior negative component (ERAN) which is known to occur in response to musically unexpected chords (Koelsch et al. 2000), and found that the ERAN was larger in the musically trained group than in the untrained group. Thus, some of the brain differences seen in harmonic processing between adult musicians and nonmusicians are present at least as early as 11 years of age.

Very little is known about the effects of musical training on enculturation to scales and harmony in preschool children. To address this question, Corrigall and Trainor (2009) tested two groups of 4- to 5-year-old children, the first of which had no formal music training and the second of which was just beginning music lessons at the time of the initial test. At the second test, about 1 year later, the first group still had no musical training, but the children in the second group had studied an instrument for 1 year. Of most interest in the present context, key membership and harmony perception were studied by presenting a sequence of five chords that ended (1) on the tonic chord as expected by the rules of Western harmony (standard), (2) on an out-of-key chord (tonic minor), or (3) on a chord that was within the key but not in the expected harmony at that point (subdominant instead of tonic). Children judged whether each sequence (standard, out-of-key, out-of-harmony) was a "good" or "bad" rendition from a puppet sitting in front of them. At the first test, all children rated the out-of-key chords and out-of-harmony endings more often as "bad" compared to the standard ending, providing evidence that children as young as four have some knowledge of key membership and harmony. However, of most interest, at the second measurement 1 year later, the group taking music lessons performed significantly better than the group not taking lessons. Thus, musical training in the preschool period leads to faster acquisition of harmonic sensitivity.

In sum, both behavioral and brain-based measures indicate that children who take formal music lessons develop sensitivity to culture-specific musical features such as scales and harmony at an earlier age than children not engaged in musical training.

4.2.4 Summary of the Development of Musical Pitch Acquisition

Certain universal musical features, such as the harmonic structure of pitch and consonance and dissonance are processed by very young infants. However, it takes several years for children to acquire system-specific knowledge of scale structure and harmony. Formal musical training is not necessary for this as people acquire system-specific knowledge of musical pitch structure through passive everyday exposure. At the same time, the research indicates that those with formal musical training in childhood develop enhanced processing for musical pitch as reflected in superior perceptual discrimination as well as in enhanced brain structures for processing music and functional brain responses to musical pitch. There is some suggestion that there might be a sensitive period for musical pitch acquisition that ends around 10–12 years, but this evidence is far from conclusive. However, it has been established that robust effects of musical training can be seen already in pre-school children who engage in learning to play a musical instrument.

4.3 Rhythm

4.3.1 Development of Metrical Perception: Enculturation

It could be argued that rhythm is the most fundamental aspect of music – there are many styles of music with little or no pitch variation or structure, but few musical styles without a temporal organization. Rhythms consist of sequences of sound events and silences. A prominent hypothesis is that the brain uses two basic perceptual organizational processes to encode, remember, retrieve, and produce rhythmic patterns (e.g., Lerdahl and Jackendoff 1983). One is *grouping*, whereby the beginnings and ends of phrases and subphrases are determined. The second, which will be the focus in the present chapter, is the derivation of *metrical* structure. Listeners use the context of onset intervals between successive sound events, in conjunction with the duration, intensity, and pitch of sound events, to extract an ongoing metrical beat hierarchy (Jones and Boltz 1989; Large and Jones 1999). For Western music, beats at each level of the hierarchy are typically evenly spaced in time, and higher levels of the hierarchy are formed by combining every two or every three beats of the previous level, and lower levels of the hierarchy are formed by dividing each beat of the previous level into two or three beats. Metrical structure is not given directly in the stimulus, but is derived in the brain. Indeed, beats can be perceived when there is no sound event at all, and beats can be derived even when the loudest and longest sound events are off the beat, as in syncopation. At the same time, metrical extraction follows orderly rules, and even musically untrained adults show considerable agreement as to where the beats are in music, as indicated by their tapping behavior (e.g., Drake et al. 2000a; Snyder and Krumhansl 2001; Repp 2005). Adults appear to use statistical regularities in the input to extract the meter (e.g., Hannon et al. 2004).

The fundamental importance of metrical extraction for musical behavior is evident in the fact that this ability is what allows people to sing, dance, and play musical instruments together in synchrony. It also distinguishes humans from most other species. Recent evidence suggests that the few species that are able to synchronize to an external auditory beat are those who are also capable of vocal imitation (Schachner et al. 2008). This suggests that metrical structure is likely fundamental to the complex communication systems – music and language – that have evolved in humans.

In some respects, infants are precocious rhythm processors. As young as 2–5 months of age, infants are able to discriminate simple rhythm patterns (Chang and Trehub 1977; Demany et al. 1977). By 2 months, infants can discriminate the tempi of isochronous beat patterns, and show optimal discrimination around 600 ms onset-to-onset (Baruch and Drake 1997), which is similar to adults. As young as 7–9 months, infants are able to recognize rhythms across variations in tempo and frequency (Trehub and Thorpe 1989). At 6 months, infants use duration cues for grouping successive sound events into phrases (Trainor and Adams 2000). Finally, a recent EEG study revealed that even newborn infants can extract a regular beat structure from temporal patterns (Winkler et al. 2009). Specifically, in the context of a rhythmic pattern, omission of an expected downbeat produced an ERP component in the newborns that is associated with violation of expectation.

Infants can extract metrical structures at 6 months of age (Morrongiello 1984; Hannon and Trehub 2005a). They can use statistical properties to categorize rhythm patterns where sound events are more likely to occur on every second beat from patterns where sound events are more likely to occur on every third beat (Hannon and Johnson 2005). Further, at 9 months infants detect changes in pitch or timing more readily in sequences with strong metrical structures than in sequences with weak metrical structures, indicating that metrical structure aids in encoding and processing rhythmic patterns in infancy (Bergeson and Trehub 2006).

The experience of metrical structure is intimately tied to the experience of rhythmic movement. Adults often feel a desire to move with the beat when listening to rhythmic music. There is likely a genetic basis for the interaction of movement and auditory rhythms, but there is also evidence for a learned aspect in that a person's preferred auditory beat tempo is related to his or her speed of walking (Todd et al. 2007). It has been suggested that this strong connection between auditory and movement rhythms might arise ontogenetically as the fetus and the young infant experience correlated sound and movement as they are walked, bounced and rocked (Hannon and Trainor 2007; Trainor 2007, 2008). Phylogenetically, rhythmic movement arose long before hearing, and can be seen in species as evolutionarily ancient as jellyfish.

Phillips-Silver and Trainor (2005) have argued that not only does music make people want to move, but movement can also influence how people experience a metrical structure. They presented 7-month-old infants with an ambiguous rhythm pattern that could be interpreted as being in either duple or in triple meter. Specifically, the rhythm pattern was six beats long and contained no accents other than the beginning of each six-beat group. Thus, it was metrically ambiguous as to whether the six-beat pattern was composed of three groups, each containing two beats (as in a march) or two groups, each containing three beats (as in a waltz). While listening to the ambiguous pattern, one group of infants was bounced in the arms of an experimenter on every second beat whereas another group was bounced on every third beat. After this experience linking movement to the ambiguous rhythm, those infants who were bounced on every second beat preferred to listen to a version of the rhythm with intensity accents added every second beat (as in a march) whereas those infants who were bounced on every third beat preferred to listen to a version with accents added on every third beat (as in a waltz). Because infants all heard the same ambiguous rhythm during familiarization, the preference differences indicate that infants in the two groups perceived the ambiguous rhythm as being in different metrical structures. Thus, bouncing on every second beat caused them to perceive it as a march and bouncing on every third beat caused them to perceive it as a waltz. Similar results were found for adults (Phillips-Silver and Trainor 2007).

Young infants are motorically immature, and they were bounced in the arms of an experimenter; thus, they did not produce their own rhythmic movement. This suggests that the observed movement-auditory interactions are likely to originate in an aspect of the movement that does not involve motor planning. Further studies indicate that the vestibular system, which gives us our sense of balance and location in the gravitation field, is crucial to the influence of movement on hearing. Direct galvanic stimulation of the vestibular nerve on either every second or on every third beat of the ambiguous rhythm, such that people have the sensation that their head is moving from side to side in the absence of any actual movement, also influences whether people interpret the pattern as a march or as a waltz (Trainor et al. 2009). Interestingly, the vestibular system emerges very early in development (Romand 1992), and young infants love vestibular stimulation in the form of rocking, bouncing, and being moved energetically through the air. Therefore, vestibular input is prominent during the time when musical processing first emerges.

The ability to reproduce rhythmic patterns develops through the preschool years. However, the same organizational principles appear to apply to Western children and adults: duple meters are easier than triple, rhythms containing fewer different note durations are easier, and intensity accents delineating the metrical structure improve performance. Drake found that 7-year-olds were more accurate than 5-year-olds at reproducing short rhythms, but that musically untrained adults were no more accurate than 7-year-olds (Drake 1993). From the age of 4 years, children demonstrate the ability to extract metrical structure in that they can tap synchronously to a beat (Drake et al. 2000b). Drake also found that the ability to tap synchronously to rhythm patterns improves between 4 and 11 years of age (Drake et al. 2000b). With increasing age, children also improve in their ability to tap flexibly at faster and slower levels of the metrical hierarchy, suggesting an improvement in complex metrical processing. Interestingly, the preferred tapping tempo decreases with age and with musical training, suggesting that the ability to process longer time spans improves with age (Drake et al. 2000b; McAuley et al. 2006). Little is known about younger children as they do not readily do tapping tasks. In order to test younger children's ability to move synchronously to an auditory beat, Eerola et al. (2006) recorded and analyzed the movements made by 2- to 4-year-old children to music. Although many children hopped, circled, or swayed to the music, they did not show evidence of changing the tempo of their movements to match changes in the tempo of the music. The literature suggests, then, that young infants can perceive metrical structure in music and that they link it to, and are influenced by, proprioceptive cues to movement. However, producing movement that is coordinated with an external auditory rhythm is more difficult and takes years to master.

The fact that different musical systems use different scales and harmonic structures, and that enculturation to the pitch structure of one's culture takes place through simple exposure to the music of that culture was discussed in Sect. 4.2.1. Is the same true for metrical structure? The intimate connection between movement and music suggest that our sense of rhythm in music might originate in the regularities of movements such as heartbeats and locomotion. However, there is also a learned and culture-specific aspect of musical meter as well. Many movements, such as walking, involve simple 1:1 or 1:2 metrical structures, as in a march. In Western music, 1:1 and 1:2 ratios predominate (Fraisse 1982), and Western adults are better able to detect changes in rhythms with simple meters than rhythms with more complex meters (Hannon and Trehub 2005a; Repp et al. 2005; Snyder et al. 2006). Indeed, when confronted with complex meters such as groups of 5 or 11, Western listeners attempt to approximate them with simple meters (Hannon and Trehub 2005a).

Unlike Western music, many other musical systems use complex meters, even in their folk music. Adults who grew up listening to music with such complex rhythms have no trouble processing them, as evidenced in their ability to detect subtle timing changes, even in the absence of formal musical training. For example, Hannon and Trehub (2005a) showed that Bulgarian and Macedonian adults, whose folk music contains non-isochronous meters with ratios of successive beats being, for example, 2:3 (e.g., a group of two beats followed by a group of three beats), had no problem detecting duration changes in complex rhythms typical of their culture's music. On the other hand, North American listeners were unable to detect these changes, although they could readily do so with simple meters using 1:2 ratios.

Hannon and colleagues have shown that sensitivity to system-specific rhythmic structure develops during the second half of the first year after birth. Just as 6-month-olds do not yet process pitch structures according to the scale system of their culture, 6-month-olds do not yet process metrical structures according to the structures dominant in their culture. Hannon and Trehub (2005a) showed that 6-month-old Western infants could detect changes in rhythms with both simple meters typical of Western music and complex meters typical of Bulgarian and Macedonian folk music. However, by 12 months, Western infants had lost the ability to process rhythms with complex meters, indicating that they had become enculturated to the dominant metrical patterns of the music in their environment (Hannon and Trehub 2005b). Bergeson and Trehub (2006) further showed that by 9 months, infants more readily process duple (march-like) rhythms compared to triple (waltz-like) rhythms, again paralleling their experience, as duple meters predominate in Western musical structure.

In sum, for infants, as for adults, musical rhythm is intimately connected to rhythmic movements, and infants are precocious musical rhythm processors. The evidence suggests that infants' rhythm perception becomes specialized for the specific metrical structures of their culture by 1 year of age, although experience with a foreign meter at this age will reinstate their lost ability to process it (Hannon and Trehub 2005b). It is not clear how long this period of plasticity for different rhythm types persists. However, rhythm perception and production continues to be refined through childhood even in the absence of formal musical training (Drake et al. 2000b).

4.3.2 Differences Between Adult Musicians and Nonmusicians in Musical Rhythm Processing

Consistent with the idea discussed in the preceding text that rhythm is more fundamental to music than pitch, cases of impaired rhythm processing appear to be much more rare than cases of tone-deafness (Foxton et al. 2006). That said, there is probably a wide range of rhythmic abilities in the general population, as well as a wide range of abilities to dance. To some extent, these differences are likely the result of different amounts and types of musical training. At the present time, the extent to which formal musical instruction in childhood is necessary for the development of good rhythmic perception and production skills remains unknown. However, a few brain imaging studies show that adult musicians and nonmusicians differ in their responses to rhythm. It is not known, of course, whether these differences are the result of the training experience or the extent to which those individuals with innate predispositions for good rhythmic processing gravitate to music lessons. However, they are consistent with the notion that musical training affects brain development and subsequent competence for rhythmic processing. For example, Jongsma et al. (2004) measured ERPs while sequences of woodblock sounds that contained omissions of five beats in a row at unpredictable times were presented to musicians (drummers and bass guitarists) and nonmusicians. Subjects were to tap at the time of the fifth omitted sound. The musicians showed less variability in tapping on the omitted tone indicating a better ability to keep an accurate internal beat in the absence of sound. Consistent with this, in both groups, a positive slow wave response to omitted tones was seen that showed less latency jitter in the musician group.

There is evidence that, with musical training, rhythm processing shifts from a predominant focus in the right hemisphere to a predominant focus in the left hemisphere. fMRI studies of rhythm processing reveal greater left activation in musicians than in nonmusicians (Limb et al. 2006). Using MEG, Vuust et al. (2005) found that MMN responses to deviations in fairly complex rhythms were larger on the right in nonmusicians, but larger on the left in jazz musicians. They interpreted this finding as having to do with rhythm being a communication system (similar to language) used by jazz players who must synchronize while communicating musical ideas through their improvisations. However, it could also be that the left hemisphere is simply better at the precise interval timing that trained musicians develop (Zatorre 2001), whereas the right hemisphere is critical for ordinal timing related to sequencing. Rhythm processing activates a network of auditory and movement-related regions that are similar in musicians and nonmusicians (Limb et al. 2006). What appears to differ between groups is the degree of activation, suggesting that one of the effects of musical training is simply to recruit more neurons to the tasks of perceiving and producing musical rhythms. This is also consistent with behavioral data showing that musicians and nonmusicians approach rhythmic processing in qualitatively similar ways, but that musicians, in comparison to nonmusicians, simply perform better with familiar types of metrical structures that are compatible with their musical training (Jones et al. 1995; Jones and Yee 1997).

Recent models of rhythmic entrainment suggest that the brain acts like a bank of oscillators, each of which can be driven best with different frequencies of input (e.g., Large and Jones 1999). EEG and MEG data lend support to this idea in that brain responses to sound contain rhythmic oscillations that are affected by sound input. Sound events cause bursts of evoked gamma band activity (30–100 Hz) between about 50–100 ms after sound onset. Of more interest here is induced activity, which also occurs in response to a sound, but which is not precisely time-locked to the sound (e.g., Shahin et al. 2008). Induced gamma band is thought to represent recruitment of intrinsic rhythms that occur in the absence of sound to the processing of the sound. Snyder and Large (2005) showed that induced gamma band activity can occur even when there is no physical sound, if a rhythmic sequence of sounds sets up an expectation for a sound event at that time. Gamma band activity in response to isolated tones is larger in musicians than in nonmusicians for musical tones, and develops earlier in children taking music lessons than in those not training musically (Shahin et al. 2008). Bhattacharya et al. (2001) found that gamma band synchrony is greater in musicians than in nonmusicians when listening to music, but not when listening to text or in silence. This suggests that music may be more meaningful to musicians than to nonmusicians. Recent research suggests that there are interactions between different frequencies of oscillation in the brain. Fujioka et al. (2009) found that activity in the beta band (15–30 Hz), associated with the motor system, decreased after each tone in a rhythmic sequence and slowly increased thereafter. However, it did not decrease after a tone omission. In contrast, activity in the gamma band, associated with memory and attentional functions, increased after each tone, and increased after tone omissions as well. Little is known as of yet about how oscillatory activity in the brain develops and how it is affected by musical training at different ages. However, because oscillatory activity reflects the processing of sequences over time, it is an important area for future research.

In sum, there is evidence that although musicians and nonmusicians use similar networks in the brain to process rhythm, there are substantial differences in their brain responses to rhythms, with musicians' responses typically earlier and larger. There are also laterality effects, with musicians typically using the left hemisphere to a greater extent than nonmusicians. The processes involved in rhythm perception and how they differ between musicians and nonmusicians is only beginning to be understood. There is even less work on how these networks develop, whether there are sensitive periods for the development of rhythmic brain responses, and whether sophisticated musical rhythmic behavior can be taught in adulthood.

4.3.3 Effects of Formal Musical Training on Children's Processing of Rhythm

There is very little scientific literature on the effects of formal musical training on rhythm processing in children. Drake (1993) found that by 7 years of age, nonmusically trained children were similar to nonmusically trained adults in their ability to reproduce heard binary and ternary rhythms. Adult musicians, on the other hand, were considerably better. In another study, Drake et al. (2000b) found that both child (6–10 years) and adult musicians were superior to age-matched nonmusicians at rhythmic reproduction, suggesting that musical training plays a large role in rhythmic competency. Tapping rate and flexibility to tap at different levels of the metrical hierarchy are also better in child musicians than nonmusicians. It remains largely unknown, however, the ages at which it is best to engage in musical training in order to achieve optimal rhythmic proficiency.

It is also possible that musical training might accelerate enculturation to rhythmic forms dominant in the musical system of exposure. Because rhythmic enculturation is seen in the second half of the year after birth (Hannon and Trehub 2005b; Hannon and Trainor 2007), it might be necessary to investigate effects of musical training by comparing the amount or type of musical experience infants receive. One study provides suggestive evidence that music classes can in fact accelerate acculturation to the dominant rhythms of a culture. Gerry et al. (2009) compared 7-month-old infants who were taking Kindermusik classes with infants who were not taking any infant music classes on the interaction between movement and interpretation of a metrically ambiguous rhythm. Specifically, they ran a group of Kindermusik infants through the same procedure as in Phillips-Silver and Trainor (2005), described in Sect. 4.3.1. Kindermusik classes involve parents walking, running, or otherwise moving their infants to the music on prescribed tapes. The tapes reflect Western rhythmic biases, with most of the songs being in duple meter and the rest in triple meter.

There were two interesting findings. First, on the preference test, infants in Kindermusik classes listened longer to the rhythm patterns on each trial than did infants not engaging in music classes, indicating a heightened interest in the rhythms. Second, the Kindermusik infants resembled nonmusically trained infants in that movement experience (duple, triple) to the metrically ambiguous rhythm resulted in a preference for an accented version of the rhythm that matched the movement experience (duple, triple). But only in the Kindermusik data was this effect stronger for duple bouncing than for triple bouncing. Thus, enriched experienced with movement and music in duple time at 7 months of age appears to accelerate cultural biases for duple meter.

Of course, the end of the first year does not mark the end of the ability to learn complex meters without prior exposure. Using the same methods as in Hannon and Trehub (2005a), Hannon and Trehub (2005b) have shown that a little experience with complex rhythms at 12 months reinstates the ability to process complex meters. It currently remains unknown as to when training on particular rhythmic forms needs to occur in order to acquire native processing of these forms. However, by adulthood it appears that complex rhythms are difficult to learn without prior exposure.

4.3.4 Summary of the Acquisition of Musical Rhythm

Young infants are precocious at processing musical rhythm in that they can discriminate rhythmic patterns and connect rhythmic movement with their perception of auditory rhythms. At the same time, their processing of musical rhythm becomes specialized for the rhythms in their environment between 6 and 12 months of age. Although there is little research on children, it appears that rhythmic processing for culturally relevant rhythmic structures improves during childhood. Children acquire musical rhythmic knowledge without formal training; still, compared to nonmusicians, adult musicians are better able to perceive rhythmic hierarchies and show enhanced brain responses and greater left laterality when processing musical rhythms. It remains unknown as to whether there is a sensitive period for musical rhythm acquisition, but it appears difficult for adults to perceive and produce complex rhythmic patterns if they have not been exposed to them during childhood.

4.4 Musical Emotion

For most of the population, music can elicit powerful emotions. Music appears to have the ability to lift the spirits, calm the nerves and express deep sorrow. Meyer (1956) proposed that although music does not generally refer to anything outside of the music itself, violation of musical expectations can elicit powerful emotions. Huron (2006) has expanded this idea in a theory of musical expression. Physiological responses to musical emotion confirm that music does activate limbic and cortical brain structures associated with emotion (Blood and Zatorre 2001; Peretz 2001; Schmidt and Trainor 2001). Further, people report physiological responses to music such as shivers down the spine, lump in the throat, laughter, and tears (Sloboda 1991). Direct measures of autonomic responses reveal that music affects breathing rate, heart rate, heart rate variability, and finger temperature (Nyklícek et al. 1997; Krumhansl 1997), although the exact relation between these responses and the specific emotion experienced remains unclear. Still, different ideas exist as to the nature of musical emotion. These ideas are explored detail in this volume (see Hunter and Schellenberg, Chap. 5). Here we focus on questions related to the development of musical emotions; however, theories about musical development can also inform the debate as to the nature of emotional expression in music and why it evolved. For example, one major question concerns the evolution of emotional expression through music. Trainor and Schmidt (2003) suggested that emotional expression in music may have originated in infant-directed singing, serving the purpose of strengthening the emotional bond between preverbal infants and their caretakers. Another major question for research on musical emotion concerns the extent to which emotional responses to musical features are innate and universal or learned through exposure to a particular musical system (Kivy 1980). Some musical features appear to have similar emotional effects across cultures, such as a slow tempo for sad music and a fast tempo for happy music (see Hunter and Schellenberg, Chap. 5). However, other features, such as the use of the major mode in Western music to convey happiness, appear to require familiarity with particular musical conventions. In the following sections, we explore the development of emotional responses to music in the context of cross-cultural evidence.

4.4.1 The Perception of Emotion in Music

Adults report that emotional regulation, emotional induction, and enjoyment are the main motivational factors behind music listening (Juslin and Laukka 2004). For prelinguistic infants, emotional responses to music appear to be central as well. Many studies suggest that infant-directed speech and singing communicate emotion, regulate mood, and promote child–parent bonding (Trainor 1996; Trehub and Trainor 1998; Dissanayake 2000). Infant-directed speech is often referred to as "musical" or "emotional" speech, and like infant-directed singing, it differs from adult-directed communication in a number of characteristics including higher overall pitch, slower rate and exaggerated pitch contours (Fernald 1991; Papoušek 1992; Trainor et al. 1997). Infants prefer listening to infant-directed over adult-directed speech (Werker and McLeod 1989; Cooper and Aslin 1990) and singing (Trainor 1996). Further, infants appear to be more engaged by maternal singing than maternal speech (Nakata and Trehub 2004). Indeed, the purpose of these infant-directed modifications seems to be the expression of emotion and elicitation of attention (Fernald 1993; Trainor et al. 1997; Rock et al. 1999; Trainor et al. 2000). Using music for emotional regulation appears to be a human universal, as mothers across cultures sing to their infants to calm them or lull them to sleep (Trehub and Trainor 1993; Trehub et al. 1993a,b). Thus, early in development, caregivers use music in its simplest form as a means to communicate and bond emotionally with a child who has not yet developed language.

Although infants are sensitive to the emotional aspects of infant-directed speech and singing, they are not as sophisticated as adults at perceiving emotion in music, especially in instrumental music. With regards to musical structure, there appear to be two general types of cues to musical emotion: (1) basic acoustic cues that likely have their roots in the nonverbal vocal expression of emotion and (2) learned, musical-system-specific cues that have no obvious counterpart in vocal expression (Balkwill and Thompson 1999). The basic acoustic cues are understood early in development and simply become refined with experience, and appear to be universal across musical systems, while the musical-system–specific cues develop through exposure to the music of one's culture. Each of these is discussed in the subsequent sections.

4.4.1.1 Basic Acoustic Cues

Some cues to emotional expression in music are shared with cues to vocal expression of emotion (i.e., prosody). Scherer's (1985, 1986) component process model of affective states proposed that different emotions have particular effects on the somatic nervous system, which ultimately affects the voice. Based on this model, Scherer made predictions about the acoustic cues that accompany five basic emotions (anger, disgust, fear, happiness, and sadness). These cues primarily consist of features common to both music and language such as tempo or speech rate, loudness, and timbre.

Juslin and Laukka (2003) tested these predictions by conducting a meta-analysis of 104 studies of vocal expression and 41 studies of music performance. Their primary goals were to examine whether certain basic emotions (i.e., anger, fear, happiness, sadness, and love-tenderness) could be communicated to adult listeners and to profile the patterns of acoustic cues that accompany each of these emotions. The results suggested that adults were highly accurate at identifying basic emotions expressed by the prosody of the voice both within- and cross-culturally, as well as by vocal and instrumental musical performance. In line with these findings, Juslin and Laukka found a significant degree of overlap between the kinds of cues used to express emotion vocally and musically. However, they stress that individual acoustic cues to emotion are neither necessary nor sufficient to identify specific emotions, but rather, are combined in an additive fashion to form patterns that probabilistically indicate certain emotions. The authors posit that expression in music essentially mimics vocal expression of emotion, and that these shared, domain-general acoustic cues are responsible for the bulk of the emotional message conveyed in music.

Support for the use of basic acoustic cues to emotion in music comes from cross-cultural studies of emotion perception. Balkwill and Thompson (1999), for example, found that Western listeners could identify the intended emotions of joy, sadness, and anger in Hindustani ragas of classical Indian music, and that they based their judgments on acoustic cues such as tempo, melodic and rhythmic complexity, and timbre. Balkwill et al. (2004) later extended this work to show that Japanese listeners could accurately identify the same emotions from Japanese, Western, and Hindustani musical excerpts. Again, listeners based their judgments on acoustic cues such as tempo, melodic and rhythmic complexity, and timbre, as well as loudness; however, in support of Juslin and Laukka (2003), Balkwill et al. (2004) found that these adult participants used combinations of cues to identify emotions rather than relying on individual components. Furthermore, Adachi et al. (2004) found that Japanese 8- to 10-year-olds and adults successfully identified whether Canadian 8- to 10-year-olds were intending to convey happiness or sadness through singing. Thus, it appears that certain combinations of acoustic cues are reliably used across musical systems to convey particular emotions, although future research should examine the use of these cues in a wider variety of musical systems.

The developmental question of interest is whether sensitivity to these universal acoustic cues to emotional expression in music is present early in development and whether this sensitivity is affected by maturation and experience. Unfortunately, only a few studies have examined emotional reactions to music in infancy. Rock et al. (1999) found that adults could identify whether 6- to 7-month-olds were listening to a lullaby or a play song based on the infants' behavior during each kind of song. Infants tended to focus inward, looking down, while listening to lullabies and on their caregivers when listening to play songs, suggesting that they associated lullabies with calming and sleep, and play songs with arousal and activity. In an attempt to show that infants can link emotions conveyed through music to those conveyed through visual means, Nawrot (2003) found that 5- to 9-month-olds looked longer at an emotionally concordant dynamic visual display (i.e., happy visual images) during happy music but not at sad visual images during sad music. The lack of preference for the concordant display during sad music may have reflected the infants' inability to recognize emotions conveyed by music. In particular, classical pieces composed by Mozart and Beethoven were used as stimuli, and these, in combination with the dynamic nature of the visual displays, may have been too complicated for especially the younger infants to demonstrate their knowledge (see also Schmidt et al. 2003). However, another possibility is that infants' lack of preference for the concordant display during sad music reflected infants' avoidance of engaging in sad displays of emotion in general. Schmidt et al. (2003) examined EEG responses in infants at 3, 6, 9 and 12 months of age to classical musical excerpts expressing joy, sadness and fear. Unlike with adults, who show more left activation for positive emotions and more right activation for negative emotions (Schmidt and Trainor 2001), infants' EEG responses did not differentiate the excerpts by emotional valence. It is possible that infants do not show different emotional responses to music, but it is also possible the musical excerpts were simply too complex for infants to extract emotional meaning. Of most interest, across all excerpts, music generally increased brain activity at 3 months, had little effect at 6 and 9 months, but decreased brain activity at 12 months. This pattern suggests that music has an arousing effect in early infancy, but a calming effect in later infancy.

Although we know little about emotional responses to music in infancy, there is somewhat more research with preschool-aged and school-aged children. Trainor and Trehub (1992b) showed that children as young as 4 years of age can associate music with non-musical referents in that they can choose the correct animal picture to go with an excerpt from Prokofiev's *Peter and the Wolf* and Saint Saen's *Carnival of the Animals*. Further, when asked why they made their choices, they sometimes cited the emotion expressed in the music (e.g., the wolf music was scary). Children as old as five appear to rely heavily on tempo (fast = happy, slow = sad) in their emotional judgments of music (Dalla Bella et al. 2001). Similarly, 6- to 12-year-olds largely base their judgments of happiness and sadness on rhythmic activity and articulation, and their judgments of excitement and calm on rhythmic activity and meter (Kratus 1993). Further, the development of happiness, sadness, and anger recognition in musical pieces appears to parallel the recognition of those same emotions in vocal intonation but not facial stimuli in 3- to 12-year-olds (Brosgole and Weisman 1995). A final point of interest is that when asked to sing a familiar song to convey happiness or sadness, 4- to 12-year-olds make use of domain-general cues such as tempo, loudness, and voice quality but tend to ignore music-specific cues such as the use of *legato* (singing smoothly as opposed to choppy), especially if they are younger and less experienced with music.

Taken together, the evidence suggests that vocal cues to emotional expression are heavily exploited even in instrumental music, and that adults and children can use these cues to infer the intended emotion being expressed. This may explain why adults and even children can identify musical emotions cross-culturally, despite being unfamiliar with the musical structure of that culture. While more research is needed to reveal whether infants can make use of some of these cues and how this ability develops, the available evidence suggests that children are able to make use of some basic acoustic cues to emotional expression such as tempo, rhythmic activity, and loudness.

4.4.1.2 Musical-System-Specific Cues

Despite the finding that basic emotions can be communicated quite readily through cross-culturally universal acoustic cues, culture-specific cues can also convey various emotions. For example, Sloboda (1991) outlined the emotional-physiological reactions that tend to occur in response to a number of different structural features in music through a survey of experienced listeners and found that tears were largely evoked by melodic appoggiaturas (where an expected stable tone on a strong beat is delayed by a nonstable tone in a melodic line), whereas shivers down the spine tended to be evoked to unexpected harmonies in Western music. Another primary example in Western tonal music is the use of the major mode to convey happiness and the minor mode to convey sadness (Gabrielsson and Juslin 2003). Indeed, adult listeners readily make these mode-emotion associations (Hevner 1936; Husain et al. 2002; Gagnon and Peretz 2003).

Developmental research has confirmed that the major-happy minor-sad distinction is acquired during childhood even in the absence of formal musical training. Despite showing a preference for highly consonant over highly dissonant chords, 6-month-olds did not prefer major over minor chords, even though major chords are considered to be more consonant than minor chords (Crowder et al. 1991). Thus, infants are not yet sensitive to the emotional connotations of major and minor chords, unlike both musically trained and untrained adults. Interestingly, Kastner and Crowder (1990) tested 3- to 12-year-olds and found that even the 3-year-olds could associate major melodies with positive emotions and minor melodies with sad emotions, although this ability improved somewhat with age. However, most studies have failed to find any evidence for this association until approximately 6–7 years. For example, Gregory et al. (1996) replicated Kastner and Crowder's study with 3- and 4-year-olds, 7- and 8-year-olds and adults with one modification: instead of providing listeners with four response options as in the original study (schematic faces depicting happy, contented, sad, and angry), they simply provided two (schematic faces depicting happy and sad). The researchers found that 7- and 8-year-olds as well as adults paired happy faces with excerpts in the major mode and sad faces with excerpts in the minor mode; however, 3- to 4-year-olds failed to use mode to classify musical excerpts as happy or sad. Similarly, Gerardi and Gerken (1995) found that 8-year-olds and adults were sensitive to mode in their judgments of happy and sad melodies whereas 5-year-olds performed at chance levels. Another interesting finding from this study was that only adults associated an ascending melodic contour with happiness and a descending melodic contour with sadness, suggesting that this kind of association also develops during childhood. Finally, Dalla Bella et al. (2001) conducted a study that allowed them to examine the relative effects of tempo and mode manipulations on happy-sad affective judgments in Western classical orchestral music. Adults' and 6- to 8-year-olds' judgments were sensitive to both mode and tempo manipulations, whereas 5-year-olds' judgments were only affected by tempo changes; 3- and 4-year-olds, in contrast, could not identify whether excerpts were happy or sad. These results suggest that by 5 years, tempo figures prominently in children's judgment of emotion in music, and that soon after mode also becomes an important factor.

In sum, although basic acoustic cues may predominate as the most salient cues to emotion in music, culture-specific cues can also be used in judgments of emotional expression. In Western music, the most important and widely researched of these cues is that of mode. Research has revealed that the major-happy and minor-sad associations are not yet present in infancy, and that they develop by the age of 6 or 7 years. Younger children tend to rely exclusively on basic acoustic cues such as tempo. Thus, as children acquire sensitivity to the structure of the music of their culture, so too do they acquire sensitivity to the cues to emotional expression that are based on this musical structure.

4.4.2 The Effects of Experience on the Perception of Emotion in Music

In the context of lyricized songs, evidence suggests that children as old as 10 years rely more heavily on the emotional connotations of lyrics than on particular musical features (Morton and Trehub 2007). However, other studies have examined children's perception of emotion in instrumental music on the assumption that children can base their emotional judgments on multiple musical features in the absence of accompanying words. These studies have generally found small age-related differences between 4 and 12 years of age in identification of happy and sad emotions in music. There is some evidence of a difficulty identifying angry and fearful emotions especially in younger children, a difficulty that is also reflected in adults' lower agreement on their judgments of these two emotions in music (e.g., Cunningham and Sterling 1988; Dolgin and Adelson 1990; Terwogt and van Grinsven 1991; Kratus 1993; Robazza et al. 1994). In addition, valence (positive or negative) appears to be more salient than intensity (high or low) when it comes to children's musical emotional perception (Kratus 1993) (see Hunter and Schellenberg, Chap. 5, for a discussion of models of emotional response to music). It therefore appears that children as young as four can identify basic emotions expressed by music when multiple cues to emotion are involved. It remains unknown whether immaturities in recognizing emotions in music are a function of general immaturities in emotion recognition or specific to musical materials.

Generally, musical training appears to have little effect on emotion perception in music. This is evident, at least, with regard to recognition of basic emotions in adults (Hevner 1935; Edmonston 1966). Similarly, neither has musical training been found to affect emotion recognition in children (Terwogt and van Grinsven 1991; Robazza et al. 1994). Sloboda (1985) has suggested that effects of musical training play a role only in the identification of more subtle or more secondary emotions conveyed in music, which may explain why most studies that examine basic emotion recognition fail to find any effect of musical experience. This argument may extend to developmental studies that also tend to focus on basic emotions – it seems likely that more age-related differences would emerge in the identification of subtle or nonbasic emotions in music. At least one study has found a musical expertise advantage in a related domain, however. Thompson et al. (2004) conducted a series of experiments examining the identification of happiness, sadness, fear, and anger from speech prosody and from tone sequences that mimicked speech prosody. Adult musicians outperformed nonmusicians on emotion identification, especially those of sadness and fear. Seven-year-olds who had been randomly assigned initially to keyboard lessons and had recently completed 1 year of musical training outperformed nonmusicians of the same age on identifications of anger and fear. As mentioned above, these also tend to be the emotions that are easily confused in music.

Taken together, it appears that musical training may influence the subtleties of emotion perception in speech and music, but that even untrained listeners are highly sensitive to the primary message being conveyed.

4.4.3 Summary of Development of Musical Emotion

The study of the development of musical emotion is in its infancy and, as such, many questions remain for future research to address. Research on children's perception of emotion in music has revealed that even children as young as 4 years can recognize emotions conveyed by music, and that they largely use acoustic cues that pertain to emotional expression in both speech and music. However, little is known about musical emotion perception in infants and toddlers, an area that deserves empirical attention. In addition, children also learn to use culture-specific cues such as mode to identify emotions conveyed by music. Future research should examine the developmental trajectories for other musical-system-specific cues.

Most studies have failed to find a significant effect of musical training on the perception of musical emotion, even in children. However, these studies have tended to examine the perception of basic and highly agreed-upon emotions in music. Research should therefore examine whether music lessons in childhood lead to a greater sensitivity to more subtly expressed emotions in music. Another question that remains open is whether early musical training might accelerate the acquisition of learned cues to emotional expression. By examining how the perception of musical emotion is shaped through developmental as well as musical experience, research can shed light on the universal appeal of music.

4.5 The Effects of Musical Training on Other Cognitive Skills

Over the past few decades, research on the possible cognitive, social, and emotional benefits of musical training has received a great deal of attention from educators, clinicians, and the popular media. Many claims have been made about music's ability to promote overall well-being, to improve performance in mathematics, spatial–temporal abilities, language, and memory, and of course, to generally "make you smarter." Are these claims justified? Unfortunately, much of the research investigating the benefits of music lessons has methodological difficulties that preclude the inference of causation. For example, most research has implemented correlational or quasi-experimental designs (i.e., without random assignment to experimental conditions), leaving open the possibility that any differences found between musicians and nonmusicians could be accounted for by preexisting differences between those who chose to take music lessons and those who did not. In addition, many studies have failed to include an adequate control group, simply comparing those who received musical training with those who received no extracurricular stimulation. Differences between these groups could be the result of the additional individual attention received by the music group, or the school-like nature of musical training, and differences might not be caused by the *musical* training in particular (see Schellenberg 2001 for a review of the methodological difficulties of musical training studies). Despite these problems, mounting evidence suggests that musical training does lead to small but reliable gains in mathematics, spatial–temporal abilities, language, and general intelligence. Each of these will be reviewed in subsequent sections, followed by a discussion of whether memory and attention might mediate these effects.

4.5.1 Mathematical Abilities

Despite anecdotal reports of the link between music and mathematics, in fact, little research has been conducted on the topic. That music and arithmetic may involve similar processes is not surprising given the abundance of mathematical relations in the harmonic, rhythmic and metrical aspects of music. A few correlational studies without random assignment have examined whether musicians tend to score higher on mathematical achievement tests than individuals who do not participate in any musical training. For example, Gouzouasis et al. (2007) found that high school students who participated in music classes tended to score higher on standardized tests of academic achievement, especially mathematics, and Cheek and Smith (1999) observed this effect in middle-school students who had received at least 2 years of private music lessons. These results support the link between music and math, but do not shed light on the direction of causation. Gardiner et al. (1996) attempted to address this question by testing 5- to 7-year-olds involved in a visual arts and music curriculum compared to students not in special classes. The researchers found that after 1 and 2 years of participation in the program, children in the experimental arts program outperformed controls on tests of mathematical skills, despite the finding that these children initially scored lower on mathematics tests than control children. However, since children in the experimental group also received visual arts training, musical training cannot be isolated as the driving factor behind the improvement.

Finally, Vaughn (2000) conducted two meta-analyses on 20 correlational and five experimental studies on the relationship between musical and mathematical abilities. The results of the analysis on correlational studies suggest that adult musicians tend to score higher on mathematics achievement tests than nonmusicians. Similarly, the meta-analysis of children's performance suggests that involvement in musical training leads to improvements in mathematical performance. However, as noted by the author, very few of the studies included in the meta-analyses came from peer-reviewed journals, suggesting a general lack of well-conducted studies examining the relationship between music and mathematics. In line with this observation, several peer-reviewed studies have failed to find support for the link between musical training and mathematical performance (e.g., Costa-Giomi 1999, 2004; Forgeard et al. 2008). Taken together, it appears that support is mixed for this relationship, and more research on the topic is warranted. It is possible that the inconsistencies arise because musical training affects some aspects of mathematical performance and not others. Thus, it would be useful for future studies to make a distinction between the different subskills (e.g., arithmetic, trigonometry, algebra, calculus) that are involved in mathematical ability as opposed to simply measuring mathematical achievement through grades achieved in school.

4.5.2 Spatial–Temporal Abilities

Somewhat related to mathematical skill is the ability to visualize and mentally manipulate images in space and time. The relation between this ability and music has received a good deal of attention, stemming primarily from the widely publicized "Mozart Effect" in which music listening is proposed to lead to a short-term improvement in spatial-temporal performance (Rauscher et al. 1993). Although this effect has been shown to be short-lived, somewhat unreliable, and primarily accounted for by arousal (see Schellenberg 2001, 2005 for reviews), stronger evidence exists for an improvement in spatial–temporal ability following musical training. Hetland (2000) conducted a meta-analysis of 15 studies examining the effects of musical training on spatial–temporal abilities in 3- to 12-year-olds, and another meta-analysis of eight studies on the effects of music instruction on a wider range of spatial abilities. The results of both analyses suggest that musical training does lead to significant and reliable gains in spatial reasoning. Further analyses suggest that the largest gains are found for younger children, individual as opposed to group lessons, and programs teaching standard musical notation; however, the author stressed that significant improvement was seen for all ages and all instruction types.

Hetland did not find support for several other variables that were predicted to mediate effect sizes, including socioeconomic status, length of musical training, parental involvement in music lessons, keyboard instruction, implementation of expressive movement in lessons, and inclusion of composition and/or improvisation in lessons. Further, the results could not be accounted for by experimenter bias, nonspecific effects of extracurricular musical training, preexisting differences between musically trained and untrained children, or study quality. Although the results are strong, more research is needed to verify each of the variables suspected of mediating the effect. In a similar argument to that made above in Sect. 4.5.1, Hetland called on future research to pinpoint whether certain kinds of spatial abilities are improved after musical training, or if the effect generalizes to all spatial tasks. Further, some evidence suggests that musical training may initially accelerate the development of spatial abilities, but that the advantage may later disappear as musically untrained children catch up in ability (Costa-Giomi 1999). In any case, most research seems to point to a reliable effect of musical training on spatial–temporal skills in children.

4.5.3 Language Skills

Despite correlations between musical ability and early reading skill (Anvari et al. 2002), and evidence that musical and linguistic processing share neural resources (see Patel 2008), few studies have specifically examined the effect of musical training on language skills. However, some evidence suggests that participation in musical activities leads to improvement in several linguistic abilities including linguistic pitch processing, phonological awareness, and early reading ability. For example, research suggests that musical training leads to superior linguistic pitch processing in both adults (Schön et al. 2004; Marques et al. 2007) and children (Magne et al. 2006; Moreno and Besson 2006; Moreno et al. 2008). These results may be linked to the finding that musically trained children and adults are better at processing emotional meaning from speech prosody than are untrained adults and children (Thompson et al. 2004).

Phonological awareness includes the discrimination, detection, and manipulation of linguistic sounds and has been found to be highly predictive of early reading ability (see Bus and van IJzendoorn 1999). Since this skill relies heavily on basic auditory processing, it may be unsurprising that it appears to benefit from musical training. Gromko (2005) found that after 4 months of music classes during regular kindergarten classes, children performed better than controls on a phonological awareness task. Similarly, Overy (2003) found that musical training improved phonological awareness in children with dyslexia. Further research should replicate these claims, but it is reasonable to conclude that phonological skills can benefit from musical training.

The relationship between musical training and reading is less clear. Butzlaff (2000) conducted a meta-analysis on six experimental or quasi-experimental studies to investigate whether musical education affected reading, and found a small and unreliable mean effect size. However, it would be premature to conclude that musical training has no effect on reading skills because very few studies were included in this analysis, and because each study used measures that assess different aspects of reading, such as word decoding (identifying words based on their graphemic representation) and reading comprehension. The only published study in this analysis examining word decoding ability as the outcome of interest found a strong effect of musical training in a group of poor readers (Douglas and Willatts 1994). By contrast, other studies have failed to find an effect of music education on word decoding ability (Overy 2003; Gromko 2005); however, the length of training in these studies was shorter than the 6 months of training reported by Douglas and Willatts. Thus, the apparent discrepancy in the results of studies examining reading benefits following formal music lessons probably stems from several reasons: (1) musical training is likely to be more closely tied to word decoding ability than to reading comprehension since both of the former involve mapping abstract visual symbols to sounds; (2) if this first point is true, there may be an optimal time in development (e.g., when children are first learning to read) where musical training exerts maximal benefits on word decoding, before which or beyond which the effects are likely to be reduced; (3) since reading is a complex and multi-faceted skill, longer training may be necessary to produce effects on reading in contrast to the case for phonological awareness, a precursor to reading; and (4) musical training may affect the reading abilities of normal and poor or dyslexic readers differently. Clearly, more research is needed to elucidate the relationship between musical training and reading skills.

4.5.4 General Intelligence

As has been reviewed in the preceding text, there appears to be evidence for both non-verbal and verbal benefits following musical training. This leaves open the possibility that many of these relationships may be explained by gains in general intelligence rather than specific transfer effects. Indeed, several studies have found a link between musical training and general intelligence (e.g., Costa-Giomi 1999; Bilhartz et al. 2000; Forgeard et al. 2008). In a strong test of this hypothesis, Schellenberg (2004) conducted a seminal study examining the effect of musical training on intelligence in 6-year-olds. Children were randomly assigned to 1 year of keyboard lessons, singing lessons, drama lessons or no lessons at no cost to their families (the last group received lessons the following year). Children were administered a standardized IQ test (the Wechsler Intelligence Scale for Children-III, or WISC-III) before beginning lessons and again after a year of lessons. Schellenberg found that while all children showed increases in full-scale IQ, children in the music groups (keyboard and singing lessons) improved more than children in the control groups (drama lessons and no lessons). Further, the greater gains in IQ experienced by the music groups were not limited to particular areas assessed by the WISC-III such as verbal comprehension, but rather, these gains were present across the different subtests and intellectual areas of the WISC-III. Schellenberg therefore concluded that musical training led to small but reliable gains in full-scale intelligence. As these children participated in group lessons, it is possible that individual lessons would lead to even larger effects on intelligence, since this type of relationship has been found for a subcomponent of intelligence, namely, spatial-temporal reasoning (Hetland 2000). In addition, Schellenberg (2006) later showed that the duration of music lessons in childhood was correlated with general intelligence in 6- to 11-year-old children as well as in undergraduate students, and Forgeard et al. (2008) later replicated these findings with 8- to 11-year-olds. It should be noted, however, that the results of these studies stand in contrast to those of Costa-Giomi (1999) who reported that the cognitive benefits following musical training might be short lived. Future research needs to clarify the long-term effects of musical training and to include more studies with random assignment, but the evidence thus far supports the link between musical training and general intelligence.

4.5.5 Memory and Attention

If musical training has a general effect on cognitive processing, then the mechanisms of transfer likely involve improvements in general processing mechanisms. Two prime candidates are memory and attention. Active participation in musical activities involves many different learned skills, many of which can be linked to memory and attention. For example, much of music training involves memorization of auditory patterns, visual patterns (musical notation), auditory-motor sequences such as melodies and fingering patterns, and associated verbal labels. Learning an instrument requires attending to and assessing the sounds one is producing and modifying them to match an internal model. Similarly, group performance requires musicians to simultaneously attend to musical notation as well as their own and others' sounds, matching tempo, dynamics and style while ignoring other irrelevant sources of information. Further, music-making often requires sustained attention to one activity for long periods of time. Thus, it is reasonable to conclude that music lessons are likely to actively train memory and attentional systems.

Evidence for verbal memory improvement following musical training is strong. In one retrospective study, Chan et al. (1998) compared adults who had received at least 6 years of musical training in childhood and adults who had not received any musical training. The groups were matched on age, grade point average, and years of education. The researchers found evidence of enhanced verbal memory in the musically trained group, but no differences between groups on visual memory. Similarly, Ho et al. (2003) found enhancement of verbal but not visual memory in children who had participated in music lessons compared to controls. By contrast, Jakobson et al. (2008) found that highly trained musicians exhibited better immediate and delayed recall for both verbal and visual material. Another study found superior verbal and non-verbal working memory in musically trained children compared to controls, although musically trained adults in this study only exhibited superior verbal short-term memory (Lee et al. 2007). Several mechanisms have been suggested to account for musicians' enhanced memory abilities. Jakobson et al. (2003) found a correlation between years of musical training and performance on verbal recall, an effect that they proposed was mediated by musicians' superior auditory temporal-order processing abilities. Similarly, Franklin et al. (2008) found that musicians outperformed nonmusicians on tests of long-term verbal memory, and suggested that musicians' advantage stemmed from superior verbal rehearsal mechanisms. Although more research is needed to understand exactly how memory is affected, memory is a strong candidate for the mechanism mediating general intelligence improvements following musical training.

A smaller body of research suggests that attention is also a candidate mechanism behind musical-training induced cognitive benefits. Scott (1992) found that preschoolers enrolled in music lessons performed significantly better on a vigilance-like attention task than control children who were either: (1) not involved in any organized classes or preschool, (2) enrolled in preschool, or (3) enrolled in both preschool and creative movement classes. Further, musically trained children in this study persevered longer on a task requiring them to replicate a complex block model, and they made fewer design errors than control children. Of course, causation is not clear in these studies because random assignment was not used. Fujioka et al. (2006) provided stronger evidence for a causal link in their finding that an MEG component (N2m) associated with memory and attentional processing changed more over the course of a year in children participating in music lessons than in children not participating. Similarly, Bialystok and DePape (2009) found that musically trained adults exhibited superior executive functions than untrained adults. In sum, musical training may well enhance attention, which in turn benefits cognitive development in general. Future research should examine the different aspects of attention that may be enhanced through participation in musical activities.

4.5.6 Conclusions About Benefits of Musical Training in Other Cognitive Domains

Although practical considerations often preclude research from investigating the link between musical training and other cognitive skills with experimental designs (e.g., with true random assignment), a large body of research suggests that the cognitive benefits of musical training are widespread. This is not to say that preexisting differences do not exist between children who go on to take music lessons and those who do not – in fact, it is highly likely that there are many of these such as socioeconomic status, parental education, and family involvement in musical activities. However, it appears that the benefits of musical training can in some cases go above and beyond these initial differences. As music is a multifaceted and complex set of skills involving perception, cognition, and emotional expression as well as individual practice and group performance, it is perhaps not surprising that extensive musical training can benefit other domains.

4.6 General Conclusions

Musical acquisition has a very long developmental trajectory. Sensitivity to some aspects of music can be seen in early infancy, such as sensitivity to consonance, relative pitch, and discrimination of simple rhythm patterns. Other aspects, such as sensitivity to harmony, do not reach adult levels until well into the teenage years. The developmental trajectory and the level of musical competence achieved depend heavily on musical experiences. Everyday exposure to a particular musical system cultivates specialized processing of the musical structure of that system. Formal musical training appears to accelerate musical development, cultivate specialization, and affect the development of networks in the brain for processing music, with the end result in adulthood of greater perceptual skills and performance ability. Formal musical training also affects executive functions such as memory, attention, and inhibition, and leads to benefits across a wide range of cognitive processes.

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