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Are There Critical Periods for Musical Development?

ABSTRACT: *A critical period can be defined as a developmental window during which specific experience has a greater effect than at other times. Musical behavior involves many skills, including the basic encoding of pitch and time information, understanding scale and harmonic structure, performance, interpretation, and composition. We review studies of genetics, behavior, and brain structure and function in conjunction with the experiences of auditory deprivation and musical enrichment, and conclude that there is more supporting evidence for critical periods for basic than for more complex aspects of musical pitch acquisition. Much remains unknown about the mechanisms of interaction between genetic and experiential factors that create critical periods, but it is clear that there are multiple pathways for achieving musical expertise. © 2005 Wiley Periodicals, Inc.* Dev Psychobiol 46: 262–278, 2005.

Keywords: *critical period; tonotopic map; pitch acquisition; musical enrichment; auditory deprivation; spectral structure; musical expertise*

INTRODUCTION

The last decade has seen an explosion of research on the perception and cognition of music (Deutsch, 1999; Juslin & Sloboda, 2001; Peretz & Zatorre, 2003; Wallin, Merker, & Brown, 2000; Zatorre & Peretz, 2001), and one of the primary questions raised concerns about the potential benefits of musical training in childhood (Schellenberg, 2003). While there is a general belief that early musical experience and training is necessary for reaching high levels of musical expertise, there is actually little direct evidence on this question.

A critical or sensitive period can be defined as an age window during which a particular type of experience has a much more pronounced effect on the development of a behavior or ability than the same experience at other times (Baily, Bruer, Symons, & Lichtman, 2001). For example, the pioneering work of Hubel and Wiesel (1970) indicated that kittens deprived of visual input to one eye for the first 6 weeks after birth have substantial visual deficits for life whereas deprivation at any other time has no such profound effect. Similarly, rats or kittens deprived of normal auditory stimulation with spectral (i.e., frequency or pitch) patterning for the first few weeks after birth develop abnormal tonotopic maps (orderly spatial layout of neurons by frequency of best response) in cortex whereas deprivation at other times does not affect this development as substantially (Harrison, Stanton, Nagasawa, Ibrahim, & Mount, 1993; Zhang, Bao, & Merzenich, 2002).

The perception and cognition of music is, of course, much more complex than the development of tonotopic maps. Music involves two major aspects: temporal (or rhythmic) structure and spectral (or pitch) structure. Both are multidimensional, involving several layers of complexity, and both have aspects that are common across different musical systems and aspects that are musical-system specific. For example, across all musical systems, rhythm has two components: (a) a grouping structure by which successive sound events are segmented into hierarchical phrases and (b) a metrical structure consisting of an abstracted regular pulse or beat in which the sound events are interpreted (Lerdahl & Jackendoff, 1983);

Received 30 July 2004; Accepted 30 November 2004
Correspondence to: L. J. Trainor
Contract grant sponsor: National Sciences and Engineering Research Council of Canada
Contract grant number: 197033-04
Contract grant sponsor: Canadian Institutes of Health Research
Contract grant number: MOP42554
Contract grant sponsor: International Foundation for Music Research
Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/dev.20059

however, some musical systems use primarily subdivisions into groups of two or three beats (e.g., Western tonal music) whereas others use much more complex subdivisions into groups of, for example, 7 or 11 beats, and incorporate frequent polyrhythms, or simultaneous conflicting beats (e.g., African music). Similarly for spectral structure, virtually all musical systems base their pitch structure on octave (2:1 frequency ratio) similarity (e.g., notes an octave apart are functionally equivalent in Western music and have the same note name) and divide the octave into a small number of unequally spaced pitches (forming the notes of a scale) from which music is composed; however, the particular division of the octave differs from musical system to musical system, as does the presence and complexity of harmonic (i.e., simultaneous tones) pitch structure (Dowling & Harwood, 1986; Krumhansl, 1990).

The multifaceted nature of musical structure, and the combination of general and musical-system-specific learning, greatly complicate an analysis of critical periods for musical development. At the same time, there is suggestive evidence that for some abilities necessary for musical expertise, early experience does have different effects than the same experience at a later time. This review will focus exclusively on spectral (pitch) structure and will highlight a few areas in which some empirical data are available. It is not meant to be a comprehensive review, but rather will focus on a few studies and consider what they tell us about critical periods. Specifically, we begin with a consideration of the development of basic musical-sound encoding in auditory cortex, move to a review of factors affecting absolute versus relative pitch development, review the orderly acquisition of musical pitch structure from sensitivity to consonance, to scales, and to harmony, and end with speculations as to the multiple possible routes to musical expertise.

EFFECTS OF EXPERIENCE ON THE DEVELOPMENT OF AUDITORY CORTEX

Effects of Auditory Deprivation on Auditory Cortex

Sensitivity to the spectral aspects of musical structure depends critically on the development of a detailed representation for pitch. Musical sounds are normally complex in that they are made up of several different frequency components. In sounds with pitch, the frequencies of the components are generally at integer multiples of a fundamental frequency (e.g., an *A* in western music has energy at 440, 880, 1760, 3520, . . . Hz). The encoding of pitch in the nervous system involves two mechanisms: (a) a temporal code whereby the firing patterns of neuronal groups reflect the period (1/frequency) of the frequencies presented and (b) a spatial code whereby different frequencies of sound maximally excite the basilar membrane at different points along its length, such that different frequencies are processed in different channels of neurons, channels that are maintained through subcortical structures and into primary auditory cortex.

The temporal code works best for lower frequencies because temporal limitations of neuronal firings create ambiguities at higher frequencies, and the spatial code works best for higher frequencies. The temporal code is likely the more important for musical perception (Moore, 2003), and the range over which it is effective corresponds to the range of musical pitch perception (i.e., the range of the piano). For tones higher or lower than this, pitch discrimination is poor (Moore, 2003). Our understanding of how the spatial and temporal codes interact and how frequencies combine to form single pitch percepts is not advanced. At the level of auditory cortex, the main spectral structuring that has been consistently uncovered experimentally is that of tonotopic maps, in which the best response of neurons moves from low to high frequencies as one travels across each map; therefore, in this review we will concentrate on this aspect of spectral pitch encoding.

Frequency discrimination in humans does not reach adult levels until well into childhood (Jensen & Neff, 1993; Maxon & Hochberg, 1982), and improves earlier for high than for low frequencies (Olsho, 1984; Olsho, Koch, & Halpin, 1987). Human infants combine frequencies into complex pitch percepts (i.e., integrate different frequency components into a single tone) by 7 months of age (Clarkson & Clifton, 1985; Clarkson, Clifton, & Perris, 1988), but there is no evidence to date that they do so at younger ages (Bundy, Colombo, & Singer, 1982). The fact that improvements in processing the spectral structure of sound can be seen for years in humans suggests the possibility of a critical period during which spectrally varied sounds must be experienced for normal pitch perception to develop.

The tonotopic maps in auditory cortex are likely too coarse to, by themselves, encode the fine-frequency information necessary for musical pitch perception. It also is not clear whether they are based on individual frequencies or on the pitch derived from complex tones consisting of several frequencies (Pantev, Hoke, Luetkenhoener, & Lehnertz, 1989). Nonetheless, animal work on the effects of auditory experience on cortical development has focused on the development of tonotopic maps. We will therefore examine this literature for information about critical periods. However, note that temporal encoding may be more important for musical pitch perception, but we know little about how it is affected by experience.

A number of studies have now indicated that the development of cortical tonotopic maps depends critically on the experience of sounds with spectral patterning early in life (Weinberger, 2004). For example, Harrison et al. (1993) demonstrated that an induced high-frequency hearing loss in neonatal kittens resulted in distorted cortical tonotopic maps with expanded cortical space devoted to frequencies near the frequency of the hearing loss. At the same time, a certain amount of plasticity remains in adults. For example, owl monkeys trained at specific frequency discriminations show, after thousands of trials, increased cortical areas that respond to those frequencies (Recanzone, Schreiner, & Merzenich, 1993), and the degree of reorganization depends on the behavioral relevance of the stimulus (Rutkowski, Than, & Weinberger, 2002).

To address the issue of critical periods for tonotopic map development, comparisons must be made between animals deprived of patterned auditory experience at different ages. Zhang et al. (2002) presented two groups of rats exclusively with pulsed white noise for a period of 20 days and compared them to control animals receiving normal sound stimulation. Pulsed white noise contains some temporal patterning, but no spectral patterning. One experimental group began this special experience at postnatal Day 9 while the other group began at Day 30. The younger experimental group, in comparison to the control group, showed broadened tuning curves and substantial impairment in the formation of cortical tonotopic maps. They also showed a reduction in synchronized firing across neurons, suggesting impairment in the development of local cortical circuits. By contrast, the older experimental group showed no such deficits. On the basis of these results, Zhang et al. argued that there is a critical period for the formation of tonotopic maps during which spectrally patterned input is necessary for normal development, and that this period ends around 30 days of age in the rat.

There are a number of possibilities for the mechanism by which the critical period ends. One possibility is that the genetic regulation of neurochemicals allows for rapid changes during the first weeks after birth, but that this period of plasticity ends through changes in the levels of these regulatory substances. Another possibility is that the experience-based organization of cortex itself results in decreased plasticity. Such a notion is consistent with Waddington's (1971) description of the epigenetic landscape whereby the earlier in development, the more choices there are of developmental paths. In other words, once a particular set of choices is made, future choices become more restricted. The notion also is consistent with the behavior of artificial neural networks, in that it is easier to teach a "naïve" network with random connection weights a particular task than a network that has been trained in a conflicting task and is no longer randomly connected. Chang and Merzenich (2003) investigated this issue in a follow-up to the Zhang et al. (2002) study described previously. This time, instead of presenting sounds with temporal patterning (pulsed white noise), they exposed rat pups solely to continuous white noise beginning at either a young or an older age. Under these circumstances, rather than developing abnormal tonotopic maps, the younger group maintained immature tonotopic organization. Furthermore, when these animals were subsequently exposed to a normal sound environment, after the supposed critical period had ended, they developed normal tonotopic representations similar to adults. These results strongly suggest that at least in rats, the end of a critical period for tonotopic representation may come about primarily through experience-based increasing cortical organization rather than through a genetic timetable of maturation that regulates the production of neurochemicals affecting neural plasticity.

An important question concerns whether plasticity in human auditory cortex follows similar rules to that of rats. Parallel to studies of visual deprivation, in which children treated for cataracts at different ages are compared (see Lewis & Maurer, this issue), one way to study the effects of auditory deprivation at different stages of development in humans might be to study children with profound hearing loss who are fitted with cochlear implants at various ages. Unlike in the visual case, cochlear implants do not come very close to restoring normal hearing. In particular, the number of frequency channels is severely limited compared to an intact ear, and the fine temporal structure of the sound input is largely lost. Nonetheless, the development of evoked responses in cochlear implant patients in comparison to normal-hearing individuals reveals some interesting insights into critical periods in the development of auditory cortex. To interpret the deprivation data, it is necessary to first characterize the normal development of evoked responses.

In children with normal hearing, auditory cortex shows a very protracted developmental period. Electrical potentials generated by the synchronous depolarization of groups of neurons can be measured noninvasively at the scalp by electroencephalography (EEG). Figure 1 shows event-related potentials (ERP) derived from EEG recordings in response to piano tones in children between 4 years of age and adulthood (Shahin, Roberts, & Trainor, 2004). It can be seen that the P1 component, which likely reflects activity in the middle layers of primary auditory cortex (Yvert, Crouzeix, Bertrand, Seither-Preisle, & Pantev, 2001), is clearly present in the youngest children, increases somewhat in amplitude with increasing age, and reaches a maximum around 9 years of age. On the other hand, N1 and P2, which likely reflect activation of secondary auditory cortical areas, and which

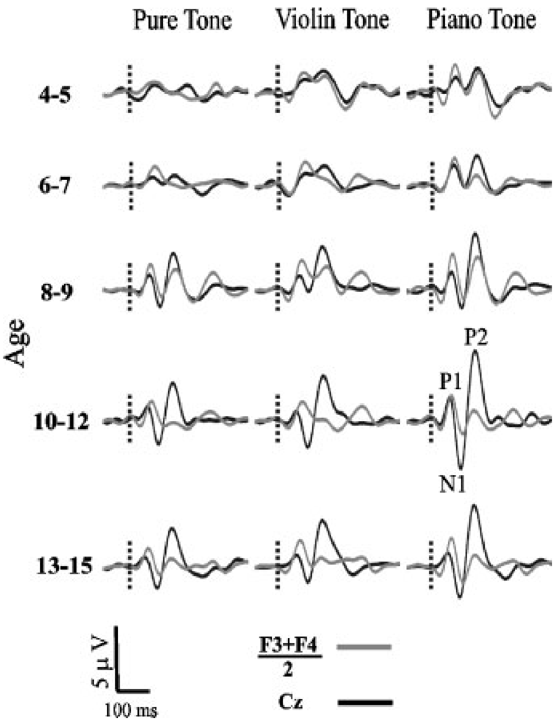

FIGURE 1 Development of auditory evoked potentials elicited by violin, piano, and pure tones. Tone onset is indicated by a dotted vertical line. P1 reaches a maximum at frontal sites (F3, F4) at 8 to 9 years, and N1 and P2 at the vertex (Cz) at 10 to 12 years. From ''Enhancement of auditory cortical development by musical experience in children,'' by A. Shahin, L. E. Roberts, and L. J. Trainor, 2004, *NeuroReport*, *15*, p. 1918. Copyright 2004 by Lippincott, Williams, & Wilkins. Reprinted with permission from the authors.

may reflect communication between cortical areas, are absent at the youngest ages, increase dramatically after age 6, reach a maximum around 10 to 12 years of age, and decrease thereafter, while remaining prominent into adulthood. Furthermore, physiological data collected by Moore and Guan (2001) showed that neurofilament maturation, which allows neurons to conduct electrical signals quickly, begins in layers 2 and 3 around 5 or 6 years of age and reaches adult levels around 12 years of age, a time course which parallels that of N1/P2 maturation (Ponton, Eggermont, Kwong, & Don, 2000; Trainor, in press). In a series of studies summarized in Eggermont and Ponton (2003), it has been shown that the P1 develops relatively normally after cochlear implantation, with the development simply delayed by a period equal to that of the deprivation. This appears to parallel the findings in rats reported earlier in which depriving the animals of patterned spectrotemporal input simply retards cortical development. On the other hand, however, Eggermont and Ponton also found that after a substantial period of deprivation, N1 never developed after cochlear implantation.

From these studies, we can conclude that cortical maturation depends on the experience of patterned spectrotemporal input. The experience of abnormal spectrotemporal patterns will result in abnormal cortical development. However, the question of critical periods for this experience is complex. At least for some aspects of cortical development (tonotopic maps in rats, development of P1 in humans), plasticity (i.e., or sensitivity to input) can be maintained indefinitely if the input contains no spectrotemporal patterning, suggesting that an end to plasticity with normal auditory input occurs as a result of the organization of neural circuits themselves. For other aspects of cortical development, reflected in the N1/P2 ERP components, there does appear to be a critical period, and prolonged deprivation results in the permanent immaturity of the processes reflected by these components.

Effects of Musical Training on Auditory Cortex

In the last section, critical periods were considered in the context of auditory deprivation. The flip side of this is to consider critical periods for specialized or enriched auditory experience. The study of the effects of musical training on the brain provides a way of looking at this question, and a number of studies have compared brain anatomy and functional responses in musicians and nonmusicians. The vast majority of these studies have examined adults, and we first review these with respect to the question of critical periods. We then turn to the few studies examining the effects of musical training in children.

Recent studies have revealed that musical stimulation activates a large network of areas (e.g., Blood & Zatorre, 2001; Halpern & Zatorre, 1999; Koelsch & Friederici, 2003; Griffiths, 2003; Parsons, 2003; Zatorre, 2003). Furthermore, anatomical magnetic resonance imaging and positron emission tomography studies indicate volumetric differences between musicians and nonmusicians in primary auditory cortex (Schneider et al., 2002), planum temporale (Schlaug, Jäncke, Huang, & Steinmetz, 1995), Broca's area (Sluming et al., 2002), and motor areas associated with the instrument of practice (Amunts et al., 1997). In particular, Schneider et al. found that bilateral differences in parts of Heschl's gyrus were 130% larger in musicians than in nonmusicians. Furthermore, the size of these areas was correlated with behavioral performance on a melody discrimination task, indicating that this increase is functionally relevant to musical skill.

The question of whether these differences are acquired through training during a critical period or are largely genetically determined remains unknown. Differences in planum temporale size between musicians and nonmusicians are due mainly to differences in whether relative or absolute pitch is the primary encoding strategy, and these will be discussed in the next section when critical periods for the development of absolute pitch are considered. The Sluming et al. (2002) study of Broca's area is interesting because musicians and nonmusicians between 26 and 66 years of age were tested. The amount by which the area of interest was increased in the left hemisphere was correlated with number of years of musical practice. Furthermore, normal volumetric reductions in specific cortical areas with older age appeared to be arrested in the older musicians. These interesting results point to the experience-dependent nature of the musician/nonmusician differences, and suggest that a substantial amount of plasticity remains in adulthood. But they do not inform us as to whether there is a critical period in childhood such that without musical training during this period, the changes observed with musical practice in Broca's area will not occur.

The strongest evidence from these anatomical studies for a critical period in childhood comes from the studies of motor cortex (Amunts et al., 1997). In these studies, the size of an area of motor cortex (intrasulcal length of the posterior bank of the precentral gyrus) in a group of keyboard players was correlated with the age of onset of musical lessons. Of course, it is possible that a genetically determined large motor cortex was responsible for the attraction to early music lessons, but the correlation is at least consistent with the existence of a sensitive period for the development of motor skills associated with keyboard playing.

Studies examining functional brain responses to sound also reveal differences between musicians and nonmusicians. The temporal resolution of ERP and magnetoencephalography studies can reveal the stage of processing at which musicians differ from nonmusicians. Differences have been reported at the level of sensory encoding in both primary (increased steady-state responses: Schneider et al., 2002) and secondary (increased N1 responses: Pantev et al., 1998; increased P2 responses: Shahin, Bosnyak, Trainor, & Roberts, 2003) areas of auditory cortex; at the level of automatic auditory change detection (increased MMN(m) or ERAN response: Brattico, Näätänen, & Tervaniemi, 2002; Fujioka, Trainor, Ross, Kakigi, & Pantev, 2004; Koelsch, Schmidt, & Kansok, 2002); and at the level of conscious evaluation (increased P3 or late positivity: Besson & Faïta, 1995; Trainor, Desjardins, & Rockel, 1999). Some of these studies also report correlations between the size of the musicians' neurophysiological responses and the age of onset of music lessons (Pantev et al., 1998; Trainor et al., 1999), suggesting that a critical period for attaining the brain changes associated with musical expertise may end around 10 years of age; however, because these are correlations, it also is possible that very early preexisting differences between the musician and nonmusician groups may have dictated the decision to engage in early musical training.

However, two lines of evidence argue against a primarily genetic basis for the musician/nonmusician differences. The first line examines differences between different types of training. Pantev, Roberts, Schulz, Engelien, and Ross (2001) showed that the increased N1 response of musicians to musical tones was specific to the timbre of the instrument of training. In particular, violinists showed increased responses to violin tones whereas trumpet players showed increased responses to trumpet tones. The second line of evidence comes from training studies that demonstrate the neuroplasticity of the responses that are larger in musicians. Bosnyak, Eaton, and Roberts (2004) trained a group of nonmusicians in making a fine pitch discrimination at 2000 Hz and found a significant increase in the P2 response from before to after the training that was specific to the trained frequency. This plasticity demonstrates that musical experience could well affect the processes underlying the P2, although it suggests that if there is a critical period, a certain amount of plasticity remains for life.

The most direct way to test for critical periods for the effects of musical experience on the brain would be to randomly assign some children to music lessons at various ages, and to follow their musical development into adulthood. Such a study does not exist, and indeed, it would be difficult to control for music experience outside of the lessons; however, Shahin et al. (2004) conducted an initial study in which a group of 4- to 5-year-old children about to begin Suzuki music lessons (6 pianists, 1 violinist) was compared to a group of age-matched nonmusician children. The ERP responses of each child in the absence of attention (children watched a silent video) to violin, piano, and pure tones were measured at the beginning of the study and 1 year later. Larger P1, N1, and N2 components were found in the Suzuki group across both measurements (Figure 2). While the fact that the groups differed before formal music lessons appears to argue for a genetic basis for the differences, two findings argue for a role of experience. First, the environments of the two groups prior to our measurements differed dramatically, with most of the children in the Suzuki group having at least one parent who practiced music regularly in the home. Some of the Suzuki children also had taken musical classes for parents and infants, and parents prepared their children for the onset of music lessons by familiarizing them with the instrument that they would be learning. Second, some of the response modifications in the Suzuki group appeared to be instrument specific. The P1 was

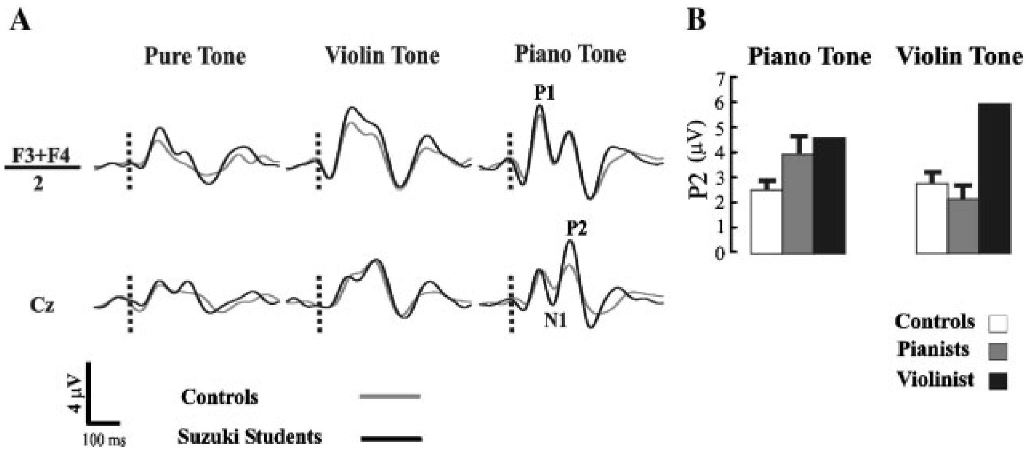

FIGURE 2 Auditory evoked potentials in 4- to 5-year-old Suzuki-trained and nonmusician children. N1 and P2 amplitude are enhanced in the Suzuki group only for piano tones (Six of the 7 Suzuki students played piano.) The dotted vertical line denotes tone onset (A). Timbre specificity. P2 amplitude evoked by the piano tones is larger in the Suzuki pianists ($n = 6$) than in the nonmusicians ($n = 6$), but P2 evoked by the violin tones is not. P2 amplitude evoked by the violin tone is largest in the violinist ($n = 1$) compared to the other groups and to P2 evoked by piano tones (B). From "Enhancement of auditory cortical development by musical experience in children," by A. Shahin, L. E. Roberts, and L. J. Trainor, 2004, *NeuroReport*, *15*, p. 1919. Copyright 2004 by Lippincott, Williams, & Wilkins. Reprinted with permission from the authors.

larger in the child musicians for all tones; however, the N1 and P2 were only larger in the piano group for the piano tones. Furthermore, the single violinist had the largest P2 response of all subjects to the violin tone (more than 2 *SD*s above the mean), but his response to the piano and sine tones were comparable to the other children (Figure 2). This study suggests, then, that the effects of musical experience on the development of auditory cortex can be seen as young as 4 years of age, but it does not tell us whether there is an upper age cutoff above which musical experience has a much smaller effect.

In summary, there is much suggestive evidence from correlations between brain responses and the age of onset of musical lessons, from the specificity of enhancements to the timbre of the instrument of practice, and from early brain differences between musician and nonmusician children that musical experience early in life has a more profound effect than musical experience later in life. At the same time, some aspects of cortical responses appear to remain neuroplastic well into adulthood, as evidenced by the lack of deterioration in practicing musicians with age and the modification of the P2 ERP response with laboratory training. It remains for future research to provide more definitive answers to the question of critical periods for the development of the musical brain.

CRITICAL PERIODS AND RELATIVE VERSUS ABSOLUTE PITCH PROCESSING

The encoding of individual tones is of course essential for musical perception, but the most important aspects of pitch structure are revealed in the relations between tones. In other words, the absolute pitch (fundamental frequency of each tone) matters less than the pitch distances between successive tones (relative pitch). A familiar tune, such as *Happy Birthday*, is recognizable regardless of whether it begins on C (262 Hz) or A (440 Hz) or any other note in the musical range (roughly, the range of the piano) as long as the relative pitches are correct. In fact, most adults encode melodies primarily in terms of relative pitch, easily recognizing tunes in transposition to new starting pitches. On the other hand, a few individuals, estimated at between 1 and 5 of 10,000 (Bachem, 1955; Brown et al., 2003), process musical pitch primarily in absolute terms. Such individuals can name the pitches of tones in isolation and can produce the pitch of a given note name without reference to any other tone. While relative pitch processors have some access to absolute pitch (e.g., Levitin, 1994) under some circumstances, it is qualitatively different from that of absolute pitch processors. Relative pitch processors retain some motor memory of how to produce, for example, the starting note of a familiar song (e.g., Halpern, 1989). As well, after repeated exposure to a song always at the same pitch level, relative pitch processors have been reported to be 58% correct (with chance performance at 50%) at identifying a version of the song at the original pitch in comparison to a version shifted by a semitone (Schellenberg & Trehub, 2003). Thus, relative pitch processors do have some limited access to absolute pitch information, but it is not comparable to the performance of those with absolute pitch.

Absolute pitch ability has at times been considered to be a special musical gift; however, many consider it to be a musical hindrance because it can take attention away from the relative pitch relations that are critical to musical structure. Indeed, some people with absolute pitch can have trouble identifying relative pitch in tonal contexts (Miyazaki, 1993) and tend to continue using absolute pitch in situations where relative pitch is required (Miyazaki, 1995; Miyazaki & Rakowski, 2002). It also is interesting in this context that monkeys and birds more readily process absolute than relative pitch (e.g., Hulse, Takeuchi, & Braaten, 1992; Izumi, 2001), given that these species have not developed language or music.

A number of studies now indicate that the brains of absolute pitch processors differ significantly from those who primarily process relative pitch. The left planum temporale in the superior temporal cortex is relatively larger than the corresponding right area in those with absolute pitch compared to those without absolute pitch (Schlaug et al., 1995), a difference that appears to be because the right areas are actually smaller in those with absolute pitch than in those without it (Keenan, Thangaraj, Halpern, & Schlaug, 2001). Interestingly, a much greater proportion of blind than of sighted musicians have absolute pitch (Hamilton, Pascual-Leone, & Schlaug, 2004), suggesting that the greater cortical space available for sound processing in blind musicians may increase the chance of developing absolute pitch. Furthermore, functional imaging studies indicate increased activation during pitch processing in absolute compared to relative pitch processors in the posterior dorsolateral cortex, an area thought to be involved in memory associations (Zatorre, Perry, Beckett, Westbury, & Evans, 1998). Event-related EEG studies also indicate differences in brain responses to pitch, with absolute pitch processors showing a greatly reduced P3 response to pitch change compared to relative pitch processors (Hantz, Crummer, Wayman, Walton, & Frisina, 1992; Hirose et al., 2002; Klein, Coles, & Donchin, 1984). This again suggests that those with absolute pitch encode isolated pitches rather than the relations between pitches.

Of most interest in the present context is the question of the developmental origins of absolute and relative pitch processing. It is extremely hard, if not impossible, to teach absolute pitch to adults, and adult learners never achieve the effortlessness and permanence of the ability as those who manifested it earlier in life (Bachem, 1940; Crozier, 1997). This suggests that either absolute pitch has a strong genetic component and/or it must be learned before some critical period. The presence of absolute pitch as measured in adulthood is strongly associated with early musical lessons before the age of 6 years (e.g., Takeuchi & Hulse, 1993), raising the possibility that there is a critical period for the acquisition of absolute pitch that ends around 6 years of age. Furthermore, specific training on absolute pitch is more successful with children under 6 than over 6 years of age (Crozier, 1997). It also has been reported that there is greater consistency in the pitch at which speakers of tone languages reproduce a given word in comparison to the reproductions of speakers of nontone languages (Deutsch, Henthorn, & Dolson, 2004; but see Burnham, et al., 2004); however, as different speakers use different absolute pitches, understanding the pitches of the tones in tone languages is a relative pitch task, and within-speaker consistency in reproduction is probably based on motor rather than perceptual memory. The most pressing question to answer is why most children who speak a tonal language or study music at an early age do *not* develop absolute pitch. A critical period hypothesis must explain why, even with the same musical experience, only a few develop absolute pitch. One possibility is that a few people have a genetic predisposition for developing absolute pitch, which is realized if they receive the appropriate experience before the end of a critical period around 6 years of age. Indeed, familial aggregation, after musical environment has been accounted for, suggests that there is a genetic component to absolute pitch (Baharloo, Johnston, Service, Gitschier, & Freimer, 1998). Furthermore, the incidence of absolute pitch is much higher in autism, which is generally thought to be a genetically-based disorder in which one of the characteristics is to focus on local rather than global aspects of complex visual stimuli (Rimland & Fein, 1988). The presence of absolute pitch in autistic children is associated with their ability to process visual details (Heaton, Hermelin, & Pring, 1998), and it is easier to teach absolute pitch to autistic than to nonautistic children (Heaton et al., 1998). The idea of a genetic origin also is strengthened by the finding that musicians with absolute pitch who do not have autism nonetheless show a greater incidence of perceptual, language, and personality characteristics associated with autism (Brown et al., 2003).

There are many possible explanations for why absolute pitch only develops in a small percentage of people; here, we will consider four main theories. One possibility, the *learning explanation*, is that absolute pitch is learned and that there is a critical period before the age of 6 years for this learning; however, while this theory is consistent with the association between early musical training and absolute pitch and with the difficulty of learning absolute pitch in adulthood, it has difficulty explaining why the majority of children who study music from an early age do not develop absolute pitch. A recent study of young Suzuki music pupils found that although young children were fairly consistent in the pitch at which they sang their violin songs from day to day, their singing pitch did not match the pitch at which the songs were played on their instrument (Saah & Marvin, 2004), suggesting that consistency in the pitch of sung renditions is based more on motor constraints than on perceptual encoding.

A second explanation is that absolute pitch is more or less genetically determined, and that given normal sound stimulation, but not necessarily special musical training before a critical period, absolute pitch will develop in individuals with a particular genetic makeup. We will refer to this theory as the *genetic explanation*. This theory would need to explain why absolute pitch is associated with early music experience. One possibility is that those with absolute pitch are attracted to music at an early age, an attraction that is noticed by their parents and leads to early enrollment in music lessons. Consistent with the genetic explanation is the possibility that there may be people without musical training who nonetheless have absolute pitch but remain undiscovered because absolute pitch is typically measured as the ability to name notes or to reproduce named notes, and those without musical training do not know the note names. Indeed, one case of such an individual has been reported (Ross, Olson, & Gore, 2002). Although this person had little formal musical training and did not know the musical note names, he could remember isolated pitches through a series of interference tones much better than relative pitch processors, and his performance was indistinguishable from that of absolute pitch processors.

A third possibility is a *maturational switch explanation*. According to this explanation, everyone is born with only absolute pitch, but most of us switch to primarily relative pitch processing as we mature (Crozier, 1997; Saffran & Griepentrog, 2001; Sergeant & Roche, 1973; Takeuchi & Hulse, 1993). Specifically, as infants and young children learn to solve invariance problems such as recognizing words across different talkers (Jusczyk, Pisoni, & Mullennix, 1992) and melodies across different singers, they switch from processing absolute to relative characteristics of speech and musical patterns. According to the maturational switch explanation, this switch from absolute to relative processing for pitch information is stopped by musical training, which emphasizes associating note names to specific pitches. Thus, learning is thought to disrupt a maturational process and prolong absolute pitch. However, the maturational switch explanation needs to explain why this switch is disrupted in only a few of the children who receive early musical training, and a genetic predisposition is probably the most likely candidate. Thus, the most reasonable interpretation of the maturational switch explanation involves an interaction of genetic and experiential factors.

A final possibility also involves an interaction between genes and experience, but in this case, infants are thought to come into the world as relative pitch processors. Absolute pitch then develops in some individuals through a genetically based predisposition to focus on local rather than global properties of stimuli in conjunction with specific musical experience in the preschool period. We will refer to this as the *interactional explanation*.

The data do not appear to support either a purely genetic or a purely experiential explanation, so the main question, then, concerns the nature of the genetic/experiential interaction. One of the most fundamental questions for understanding this interaction concerns whether infants come into the world as relative pitch processors, and a few learn absolute pitch processing before a critical period around age 6, or whether infants come into the world as absolute pitch processors, and only a few fail to switch to relative pitch processing. To evaluate which of these hypotheses is correct, the most useful data concern whether young infants are primarily relative or absolute pitch processors.

To date, the only infant studies of relative and absolute pitch are from infants 6 months of age and older. In a series of studies, Sandra Trehub and colleagues (e.g., Cohen, Thorpe, & Trehub, 1987; Trainor & Trehub, 1992; Trehub, 2001; Trehub & Trainor, 1993) demonstrated that infants process relative pitch in immediate memory. When two melodies are presented in immediate succession, infants have no difficulty telling whether they are the same or different even when the two melodies are transposed to different pitch ranges (keys) with respect to each other. Thus, infants can compare the pitch distances between tones (i.e., the relative pitch) even when the absolute pitches are changed. With respect to absolute pitch, infants can detect when a melody is transposed to a different pitch range (i.e., absolute pitch) when the time interval between comparison melodies is short, but they treat the original and transposed versions as equivalent when the interval between them is longer (Trehub, Bull, & Thorpe, 1984), suggesting that infants are using a relative, not an absolute, pitch code for storing melodies in long-term memory.

On the other hand, using a statistical learning paradigm, two other studies (Saffran, 2003; Saffran & Griepentrog, 2001) reported that infants process absolute, but not relative, pitch; however, these studies suffer from methodological issues, and can be interpreted as showing that infants do, in fact, process relative pitch.[1] It also has been reported that infants prefer to listen to a song sung at the same pitch as during familiarization in comparison to the song sung at a new pitch (Volkova, Trehub, & Schellenberg, 2004). However, when a singer changes pitch range, the timbre or quality of her voice changes as well. Infants have been shown to remember voices for at least 2 weeks (Jusczyk, Hohne, Jusczyk, & Redanz, 1993) and to remember instrument timbres for at least hours (Trainor, Wu, & Tsang, 2004). It is probable, therefore, that infants were responding to timbre and not absolute pitch in the Volkova et al. study.

Trainor and colleagues reasoned that a good test of whether infants encode pitch relations in long-term memory in relative and/or absolute terms would involve a long delay between familiarization and test, and no confound between relative and absolute pitch. They first confirmed that infants who listened to one of two old English folk songs played on a piano at home for 7 days remembered the melody (Trainor et al., 2004). Specifically, on the eighth day, they showed that infants preferred to listen to whichever melody they had not been familiarized with (novelty preference). Plantinga and Trainor (in press) then tested for relative pitch encoding by conducting the same experiment but with the melodies transposed either up or down by a perfect fifth ($\frac{7}{12}$ of an octave) or tritone ($\frac{1}{2}$ octave) at test compared to during familiarization (Figure 3). Despite the transposition, infants still showed a strong novelty preference, indicating that they recognized the familiar melody in transposition, and thus that they process relative pitch. On the other hand, after familiarization, if the two melodies at test were both the familiar melody—one at the pitch heard at home and the other at a novel pitch—infants showed no preference for either version. This shows that absolute pitch is not salient to infants under these conditions, and gives no indication that they remembered the absolute pitch.

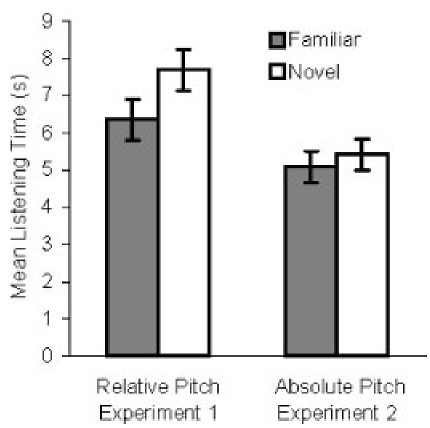

FIGURE 3 Infants' preferences, after familiarization for 7 days with one of two melodies, as measured by the amount of time they chose to listen to a novel compared to a familiar version. For relative pitch transpositions (Experiment 1), infants prefer the novel compared to the familiar melody, regardless of the transposition type (up or down a perfect fifth or $\frac{7}{12}$ s of an octave; up or down a tritone or $\frac{1}{2}$ of an octave), indicating that they remember melodies in terms of relative pitch (left panel). Infants show no preference for the familiar melody transposed to a novel pitch (up or down a perfect fifth or $\frac{7}{12}$ of an octave; up or down a tritone or $\frac{1}{2}$ of an octave) compared to the same melody at the familiar pitch (Experiment 2), indicating that either they do not remember the absolute pitch or it is not salient to them (right panel). Error bars represent within-subject variability. From ''Memory for melody: Infants use a relative pitch code,'' by J. Plantinga and L. J. Trainor, *Cognition* (in press). Copyright by Elsevier. Reprinted with permission from the authors.

[1]In Saffran, Aslin, and Newport's (1996) study of statistical learning in speech, they created three-syllable ''words,'' played with no breaks between them during familiarization, such that both pairs of syllables composing them have a high transitional probability in only one of two familiarization streams. At test, infants were tested on their recognition of words from the familiarization stream to which they were exposed versus words from the familiarization stream to which they were not exposed. There are two problems with the translation of this paradigm to the study of relative versus absolute pitch in tone sequences. First, relative and absolute pitch cannot be manipulated independently because if you change the relative pitch between two tones, by definition you change the absolute pitch of at least one of the tones. Therefore, in Experiment 2 of Saffran and Griepentrog (2001), for example, which tested for relative pitch, three-tone ''words'' were created such that both pairs of tones (i.e., first and second tones; second and third tones) were present within single words (and therefore had high transitional probabilities) for one familiarization stream whereas for the other stream, although both pairs of tones were present within words (and had high transitional probabilities), they were not present within a single word (so the probability of the triplet of tones differed across conditions). Thus, all tone pairs in the test words occurred with high transitional probability in both conditions during familiarization, but the triplets of tones comprising the test words only occurred in one, but not the other, condition. This brings us to the second problem with the translation of the statistical paradigm from speech to testing relative versus absolute pitch, which is that there is no evidence that infants group the familiarization tone streams into triplets of tones rather than pairs of tones. In fact, pairwise statistics would be easier to compute, and therefore, this is probably the major statistical information that infants in fact do encode. This is compounded by the fact that Saffran and Griepentrog defined ''pairs'' differently for relative and absolute pitch. For absolute pitch, pairs are composed of two tones whereas for relative pitch, ''pairs'' are composed of three tones (2 two-tone pitch pairs; i.e., the first and second tones and the second and third tones of the triplet). This is very misleading. If infants do in fact encode primarily two-tone rather than three-tone statistics (which is very likely), then the test items in Experiment 2 of Saffran and Griepentrog do not distinguish between the two familiarization conditions. Specifically, if you examine the relative pitches of the test words in their Table 3, you see that *all* relative pitches are equally present in both streams (specifically, P5down, M3up, M3down, P5up, M2up, P5down, P4up, M3down). Therefore, if infants encode the relative pitch of two-tone pairs (which is what they most likely do), then you would expect no difference in looking times between the two sets of test items, which is exactly what Saffran and Griepentrog found. The only way to conclude that infants are not doing relative pitch is to assume that they are encoding triplets of tone. However, the three-tone sequences also differ in absolute pitch cues between conditions, so if infants are encoding three-tone sequences, then you would have to conclude that they are doing neither relative nor absolute pitch in this case. Our conclusion is that infants in these experiments are behaving exactly as one would predict if they encoded the relative pitch of pairs of tones.

This review indicates that there is strong evidence that infants readily engage in relative pitch processing in both immediate and long-term memory tasks. On the other hand, there is no definitive evidence that infants store detailed absolute pitch information for music. On the basis of this data, it is possible that the maturational switch explanation, whereby the vast majority of infants switch from absolute to relative pitch processing, is correct; but if so, the switch must take place prior to 6 months of age. However, this does not fit with the correlations between absolute pitch ability and musical experience during the preschool period. This data is consistent, however, with the interactional explanation, which suggests that young infants are relative pitch processors, and that absolute pitch is learned during the preschool years in the presence of both a genetic predisposition and specific musical experience. It also is consistent with the genetic explanation, which postulates that the vast majority of infants are relative pitch processors from the beginning, but a few are absolute pitch processors. Given the rarity of absolute pitch, it would be expected that none of the infants tested to date in relative and absolute pitch tasks possessed absolute pitch. Support for a genetic over an interactional explanation would include finding a few infants who, contrary to the majority, primarily focus on absolute pitch information.

In summary, it is likely that there is a critical period for the development of absolute pitch that ends around 6 years of age; however, this critical period may exist strongly in only a few individuals who have a genetic predisposition for processing local as opposed to global information. For the majority, learning absolute pitch may be difficult at any age.

DEVELOPMENTAL SEQUENCE FOR THE ACQUISITION OF MUSICAL PITCH STRUCTURES

Thus far, we have considered only simple aspects of pitch encoding; however, musical pitch structure is multidimensional (Krumhansl, 1990; Shepard, 1982), with some dimensions realized quite similarly across musical systems and other dimensions quite differently. The perceptual development of three of the most basic aspects of musical pitch structure will be discussed here. The first dimension is that of sensory consonance (two or more tones that adults rate as sounding good together) and dissonance (two or more tones that adults rate as sounding unpleasant or rough together). The second dimension is scale structure, whereby notes an octave apart (a doubling of frequency) are perceived as similar and function equivalently (have the same note name), and the octave is divided into a small set of discrete tones, each of which serves a different musical function in musical composition. The third dimension is harmonic structure, whereby sequences of chords are concatenated according to particular syntactic rules.

The dimension of sensory consonance and dissonance is perceived quite similarly across musical systems. As well, 6-month-olds can categorize consonant and dissonant intervals (Trainor, 1997), prefer to listen to consonant in comparison to dissonant intervals (Trainor & Heinmiller, 1998; Zentner & Kagan, 1998), and perceive two consonant intervals to sound more similar than a consonant and a dissonant interval, regardless of the size or pitch distance between the tones in the interval (Schellenberg & Trainor, 1996). As young as 2 months of age, infants prefer to listen to consonance in comparison to dissonance (Trainor, Tsang, & Cheung, 2002). There are two theories as to the origin of the sensation of dissonance, and both involve the auditory periphery. Plomp and Levelt (1965) proposed that sensory dissonance arises from the critical band structure of the cochlea, whereby the activation patterns on the basilar membrane in the inner ear of two simultaneously presented frequencies interact when the frequencies are less than a critical bandwidth apart. Because of the overtone structure of complex tones with pitch (energy at components that are integer multiples of the fundamental frequency), and because each component in one tone can potentially interact with each component of the other tone, the net result is that tones whose fundamental frequencies stand in small-integer relations (e.g., 2:1 as in the octave; 3:2 as in the perfect fifth) sound consonant whereas those whose fundamental frequencies stand in more complex relations (e.g., 32:15 as in the major seventh; 45:32 as in the tritone) sound dissonant. In a competing theory, Tramo, Cariani, Delgutte, and Braida (2003) proposed that because of the simplicity of the frequency relations in consonant compared to dissonant intervals, the two types of stimuli set up easily distinguishable firing patterns in auditory nerve fibers. In any case, it is clear that this dimension of pitch structure is largely influenced by the structure of the auditory periphery, and develops early in life. While there is no direct evidence, it is plausible that unless basic pitch perception itself is disrupted, the perception of consonance and dissonance will develop, and any potential critical period would probably overlap that for basic pitch perception.

The second dimension, that of musical scale structure, is of more interest from a critical-period perspective. While virtually all musical systems treat notes an octave apart as equivalent, likely because they form the most consonant interval, different musical systems divide the octave into different sets of notes, separated by different pitch distances. Thus, this aspect of music pitch structure must be learned. Research shows that 8-month-old

Western infants have not yet learned the structure of the major scale, the most common scale in the Western musical system. Trainor and Trehub (1992) played an unfamiliar melody to infants and adults, repeated at different starting pitches (i.e., in different keys). Adults without musical training found it much easier to discriminate a change in one note of the melody when the change went to a note outside the scale (or key) of the melody in comparison to when the change note remained within the scale of the melody, demonstrating that even musically untrained adults have learned (implicitly) the scale structure of the music of their culture. On the other hand, the infants discriminated both types of changes equally well, outperforming adults on the within-key changes under some circumstances. These findings are consistent with studies of song production, which have shown that younger children wander considerably in pitch, but begin to use consistent tonality after the age of 5 years (Dowling, 1999).

Interestingly, infants appear to be open to learn any musical pitch system, as they show equal performance in discriminating mistunings in Western and in Indonesian scales whereas Western adults are much better with Western scales (Lynch, Eilers, Oller, & Urbano, 1990). Furthermore, at 13 years of age, children with musical training show a greater advantage for detecting mistunings in Western than in Indonesian scales compared to children with no musical training, suggesting that musical training in childhood can accelerate or enhance the learning of native scale structure (Lynch & Eilers, 1991). However, to directly test for a critical period for scale learning, it would have to be shown that children of a particular age are more easily able to learn a foreign scale structure than children of an older age; to our knowledge, such a study has not been done.

Harmony, the third dimension of musical pitch structure, is relatively rare across musical systems. Many musical systems employ a drone, or constant tone, that is repeated throughout the composition, but Western musical structure may be the only one with a complex harmonic syntax. Interestingly, this component of music pitch structure is learned relatively late in development. To Western adults, every tonal melody can be accompanied by a series of chords, and we can say that the melody implies those chords. A number of studies have shown that even those without formal musical training but who have grown up in Western culture have implicit knowledge of these rules (Tillmann, Bharucha, & Bigand, 2000). Trainor and Trehub (1994) asked 5-year-olds, 7-year-olds, and adults to detect three kinds of changes to a melody (Figure 4). In one case, the changed note went outside the scale or key of the melody; in the second case, the changed note was within the scale but was not within the correct implied harmony at that point; in the third case, the changed note remained within the key and the implied harmony at that point. The 5-year-olds easily detected the out-of-scale notes, indicating that they understood Western scale structure, but they had trouble detecting both types of within-scale changes, indicating that they did not yet understand Western implied harmony. In contrast, 7-year-olds and adults easily detected both the out-of-scale notes and the within-scale/out-of harmony notes, only having trouble with the within-scale/within-harmony notes. This suggests that sensitivity to harmonic structure develops much later than sensitivity to scale structure and is consistent with other studies of young children (Cuddy & Badertscher, 1987; Krumhansl & Keil, 1982; Speer & Meeks, 1985) and the fact that harmony is rarely taught in school settings until at least 8 years of age. Furthermore, there is evidence that sensitivity to more complex aspects of harmonic structure continues to develop until at least 10 to 12 years of age and may depend on children's developing memory and attentional skills (Costa-Giomi, 2003). It remains unknown as to whether there is a critical period for the acquisition of harmonic structure, although it has been reported that it is much easier to teach after the age of 8 years than before that age (Costa-Giomi, 2003).

In summary, there is a clear developmental trajectory to the acquisition of musical pitch structure, with sensitivity to consonance and dissonance emerging very early, sensitivity to scale structure emerging within the first few years, and sensitivity to harmonic structure beginning to emerge rather late, around 6 to 7 years of age. Interestingly, this developmental progression parallels the degree of similarity in these dimensions across musical systems, and the extent to which they are dependent on more central than peripheral parts of the auditory system. However, we know little about whether there are critical periods for the emergence of sensitivity to consonance, scales, and harmony.

CONCLUSIONS: DIFFERENT PATHWAYS TO MUSICAL EXPERTISE

Music is a complex human activity, involving many aspects and layers of complexity. Thus, there can be no simple answer to the question of critical periods for musical development. In general, more evidence for critical periods has been found to date for basic aspects of musical behavior, such as tonotopic map formation and absolute pitch perception, in comparison to more complex aspects such as scale structure, harmony, musical interpretation, and composition. Although in most children sensitivity to relative pitch and sensory consonance emerges very early in infancy, scale knowledge during the first years of life, and harmonic knowledge between

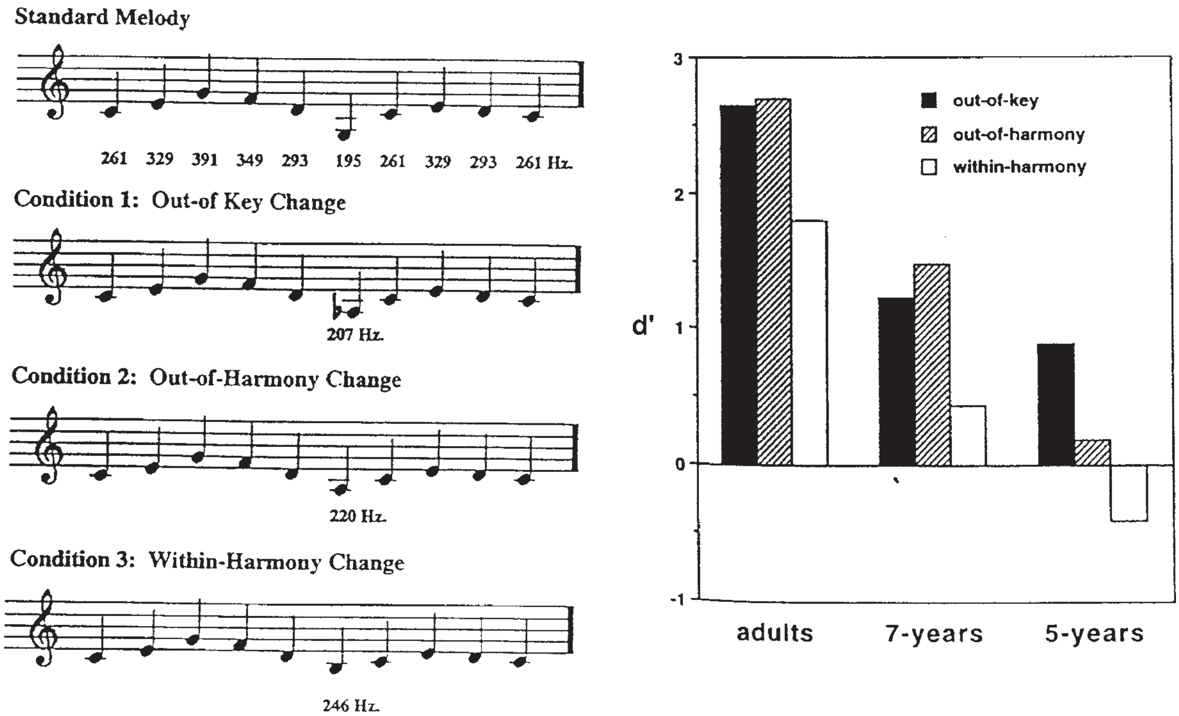

FIGURE 4 The development of scale or key knowledge and implied harmonic knowledge in children exposed to Western music. The fact that 5-year-olds, 7-year-olds, and adults find it easy to detect changes that go outside the key indicates that they represent notes in terms of key membership or scale structure. The fact that only 7-year-olds and adults, but not 5-year-olds, find it easier to detect within-key changes that go outside the implied harmony in comparison to within-key changes that remain within the implied harmony indicates that children younger than about 7 years do not yet represent melodies in terms of their harmonic implications. From "Key membership and implied harmony in Western tonal music: Developmental perspectives," by L. J. Trainor and S. E. Trehub, 1994, *Perception & Psychophysics*, *56*, pp. 128–129. Copyright 1994 by Psychonomic Society Inc. Reprinted with permission from the authors.

about 6 and 12 years of age, the effects of early enrichment or early deprivation on the emergence of sensitivity to these various aspects of music pitch structure remain largely unknown. We still do not know the answers to basic questions such as whether a person who is not exposed to music based on Western scale structure until the age of 2 years, 6 years, or older will develop the brain circuits for processing Western scales or Western harmonic structure or whether exposure to another musical system prior to this will help or hinder acquisition of Western musical structure. Furthermore, there are the exceptional cases of child prodigies who show a quite accelerated developmental trajectory. For example, it is obvious from the sophistication of Mozart's early musical compositions that he had a profound knowledge of harmony from a very early age. We still do not fully understand the origins of such exceptional development.

Of essential importance to an understanding of critical periods is an analysis of the mechanisms by which these critical periods emerge. By definition, a critical period involves both genetic and experiential factors, as it is a developmental window during which experience can have a more profound effect than at other times; however, a critical period could be under tight genetic control and involve neurochemical regulation that results in increased plasticity in certain brain areas during certain time windows. In this case, the time window for a critical period would be expected to be quite stable. On the other hand, a critical period could be more loosely under genetic control, with particular experiences themselves leading to the organization of neural circuits that in turn become stable and resistant to further change. In this case, the age window for a critical period would be expected to vary depending on the experiential history of the person. As discussed earlier, there is evidence for the latter situation in the formation of tonotopic maps, as animals exposed to unpatterned white noise show longer critical periods than animals exposed to impoverished, but patterned, sound stimulation (Chang & Merzenich, 2003). As well, the existence of child prodigies suggests that the time frame for development can be sped up considerably. On the other hand, some auditory processes likely fall more into the tight genetic control category, as different ERP components show very different recovery trajectories after a period of auditory deprivation (Eggermont & Ponton, 2003), and certain ERP components show different plasticity in childhood and adulthood (Shahin et al., 2003; Shahin et al., 2004). Furthermore, it is possible that there is a genetic contribution to how strongly a critical period may be present in an individual, as in the case of absolute pitch acquisition.

When higher levels of musical accomplishment are considered, it is clear that there are different possible pathways for musical acquisition. We still do not fully understand how the musical child prodigy or the adult master has achieved expertise. Certainly experience plays a large role. At age 21, violinists rated as excellent by their teachers had accumulated about 10,000 hr of practice compared to 5,000 hr in those who were rated as good (Ericsson, Krampe, & Tesch-Römer, 1993); however, more experience is not the whole answer. Interestingly, fewer hours of formal practice at an early age (Sloboda & Howe, 1991), perhaps allowing a more positive attitude toward practice to develop, and a positive social context for musical development (Moore, Burland, & Davidson, 2003) also are associated with adult expertise.

At the same time, not all students who practice a lot become masters, so there also may be a contribution of innate talent (Gardner, 1993); however, it also is somewhat difficult to predict musical genius from early childhood promise. There are certainly cases of child prodigies who become creative adult artists, such as Yehudi Menuhin, but there also are many cases of child prodigies who did not live up to their initial promise (see Gardner, 1993). And there are cases of adult masters who showed no exceptional talent as children. For example, Stravinsky trained to be a lawyer and did not compose seriously until after the age of 20 (Gardner, 1993). An analysis of skills in children and adults has led some to question the existence of innate talent at all, and to attribute musical success solely to experiential factors (Howe, Davidson, & Sloboda, 1998), but most argue for a genetic contribution (e.g., Baltes, 1998; Baron-Cohen, 1998; Detterman, Gabriel, & Ruthsatz, 1998; Feldman & Katzir, 1998; Oerter, 2003; Sternberg, 1998; Trehub & Schellenberg, 1998; Winner, 1998).

What can we conclude about critical periods for musical expertise? Deprivation studies certainly have indicated that it is necessary to experience spectrally and temporally patterned rich sound to wire brain circuits for pitch processing (Chang & Merzenich, 2003). And enrichment studies also have indicated that early intensive musical experience has an effect on brain development (Shahin et al., 2004). However, the adult brain also retains some plasticity (Bosnyak et al., 2004), and it appears to be at least possible, if uncommon, to acquire musical expertise later in life. Therefore, critical periods for higher levels of musical expertise are probably quite fluid, and it is clear that there are multiple pathways to achieving musical expertise.

NOTES

The writing of this article was supported by the National Sciences and Engineering Research Council of Canada, the Canadian Institutes of Health Research, and the International Foundation for Music Research. I thank Lisa Darragh for her comments on an earlier draft.

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