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Music acquisition: effects of enculturation and formal training on development

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Musical structure is complex, consisting of a small set of elements that combine to form hierarchical levels of pitch and temporal structure according to grammatical rules. As with language, different systems use different elements and rules for combination. Drawing on recent findings, we propose that music acquisition begins with basic features, such as peripheral frequency-coding mechanisms and multisensory timing connections, and proceeds through enculturation, whereby everyday exposure to a particular music system creates, in a systematic order of acquisition, culture-specific brain structures and representations. Finally, we propose that formal musical training invokes domain-specific processes that affect salience of musical input and the amount of cortical tissue devoted to its processing, as well as domain-general processes of attention and executive functioning.

Introduction

Interest in musical origins has increased dramatically in the past decade [1–4]. Fundamental to this topic is the question of how musical experiences affect development. It is clear that some aspects of musical competence, such as the ability to read music, require formal music lessons. However, just as children come to understand their spoken language, most individuals acquire basic musical competence through everyday exposure to music during development [5–7]. Such implicit musical knowledge enables listeners, regardless of formal music training, to tap and dance to music, detect wrong notes, remember and reproduce familiar tunes and rhythms, and feel the emotions expressed in music. Recent work also suggests that explicit musical instruction, in addition to enhancing music-specific knowledge, substantially affects development of basic behaviors and neural processes in a range of domains and modalities. A key goal of current research in the field is to understand the effects of experience on domain-specific and domain-general developmental outcomes (Figure 1).

Here we outline two types of experience that fundamentally shape development: (1) 'enculturation processes', in which basic auditory capacities are modified by everyday experience listening to the music of a particular culture, and (2) 'formal musical experience', through which perception and production skills are trained to a high level, and musical knowledge becomes explicit.

Enculturation: from universal to system-specific processing

Musical enculturation is the process by which individuals acquire culture-specific knowledge about the structure of the music they are exposed to through everyday experiences, such as listening to the radio, singing and dancing. Just as there are different languages, there are many different musical systems, each with unique scales, categories and grammatical rules governing pitch and rhythmic structures [8]. Additionally, there are universal, or near universal, aspects of musical structure that might reflect innate constraints working in concert with widely shared auditory experiences, such as hearing sounds with spectral (pitch) and temporal (rhythm) patterning. Sensitivity to universal aspects of spectral and temporal structure emerges early in development, whereas system-specific responses emerge later as a result of enculturation.

Learning pitch structure: from consonance to scales to harmony

Across all cultures, pitches whose fundamental frequencies stand in small integer ratios (e.g. octave, 2:1; perfect fifths, 3:2) form consonant intervals, and elicit more positive affective responses than pitches whose fundamental frequencies stand in more complex ratios (dissonances: e.g. tritone, 45:32) [9]. Sensitivity to consonance and dissonance might be universal across cultures owing to peripheral mechanisms of the auditory system that develop early in ontogeny, and enable even nonhuman animals to discriminate and categorize consonant and dissonant sounds [10,11]. Specifically, many overtones of pitches related by complex ratios are close in frequency (less than a critical bandwidth – ~1/3 of an octave) and the overlap in vibration patterns compromises the resolution of frequency on the basilar membrane, leading to beating and the perception of roughness [10]. Both adults and infants have greater difficulty discriminating pairs of dissonant than consonant intervals [5,6]. Like adults, newborns and young infants

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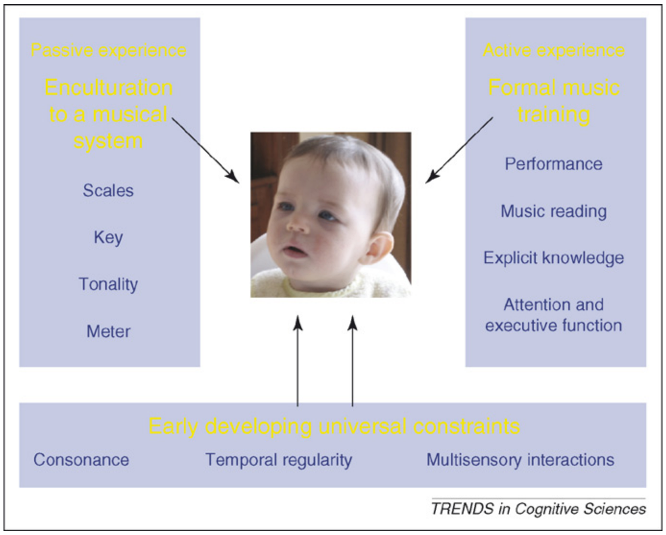

Figure 1. Certain features of musical experience, such as the pleasantness of consonance, an affinity for regular beats, and multisensory interactions between movement and auditory rhythm (bottom box), are common across cultures and are evident early in development. These features probably form the basis for musical learning. However, musical systems differ in their pitch and rhythmic structures. Passive exposure to a particular music system (left box) in childhood sets up brain structures that are functionally specialized for that structure, a process referred to as enculturation. Formal musical training (right box) has domain-specific effects on the neural encoding of musical structure, enhancing musical performance, music reading and explicit knowledge of the musical structure, as well as domain-general effects on attention and executive functioning, which can affect linguistic and mathematical development. It remains for future research to delineate the effects of specific musical experiences at specific ages on specific aspects of the auditory processing.

Box 1. Development of absolute and relative pitch processing

Most adults encode and remember melodies in terms of relative pitch (RP), that is, the pitch distances or intervals between notes of the melody, rather than in terms of individual absolute pitches (AP) (Figure I illustrates these two ways of listening). The relative pitch code is sophisticated in that it enables fast recognition of a melody regardless of the pitch range of the singer, and automatic electrophysiological responses to violations of RP structure are seen even in non-musicians [16]. Between 1 and 5 in 10 000 adults are said to have AP in that they can identify (label) and produce an isolated pitch with no reference to any other pitch [47]. A cruder form of AP, which does not involve labeling, is more widespread. For example, adults are ~60% correct at identifying the original pitch level of a familiar television show theme song presumably because they always hear it at the same pitch level [48].

Many studies have shown that infants encode pitch patterns based on RP information; for example, by ignoring transpositions but treating violations of a melody's intervallic structure as novel [5,6]. For some sequence-learning tasks, however, infants might use AP cues. When required to segment 'units' (groups of tones or phrases) from a continuous tone stream, 8-month-olds are more likely than adults to use AP information ([49], but see [5] for an alternative interpretation of these results consistent with RP processing). This finding has fueled claims that infants are born with AP but 'unlearn' it in the absence of specific music training because of the greater utility of RP for everyday music listening [47]. However, it is unlikely that infants are using the rare labeling form of AP. Although 6-month-olds remember a familiar melody, they show no evidence of remembering its pitch level [50]. Indeed, when AP cues are unavailable, infants readily use RP on sequence-learning tasks [51]. Taken together, recent evidence best supports the idea that infants and adults alike encode both relative and absolute aspects of music, such as timbre, tempo and pitch, and can use both types of information depending on the context [48,52]. Future work on the development of AP processing must disentangle relatively rare pitch-labeling abilities from more widely held abilities to process low-level stimulus attributes.

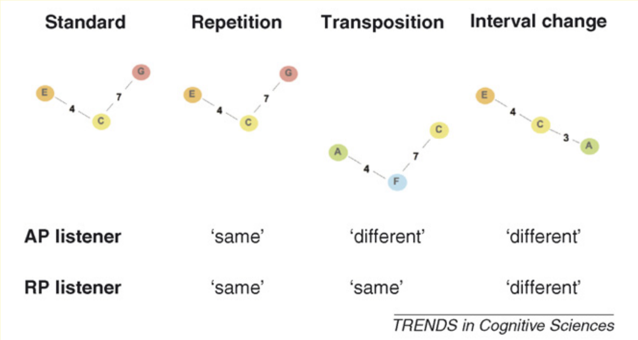

Figure I. Examples of relative and absolute pitch processing. A standard melody is given with a sequence of pitch names (E-C-G) and intervals (4–7). It is contrasted with three comparison melodies: the 'repetition' presents the same pitch and interval sequence, the 'transposition' presents a novel pitch sequence but the same interval sequence, and the 'interval change' melody presents a novel pitch and interval sequence. An RP listener would primarily attend to the interval and not the pitch sequence, and so, after an interval of time or the presentation of auditory interference tones, would consider the transposition to be identical to the standard.

show a robust preference for consonant over dissonant tone pairs [12] and musical passages [13]. Interestingly, although many species discriminate consonance and dissonance, the aesthetic preference for consonance is probably unique to humans, as shown by the absence of the preference for consonant intervals in nonhuman primates [14], who seem to dislike music in general, opting for silence over music [15].

Early sensitivity to consonance might function as an essential building block for learning the pitch structure of a specific musical system because, although musical scales differ across cultures, they are all based on prominent consonant intervals. A substantial literature suggests that Western adults, even those without formal musical training, possess implicit knowledge of the rules governing hierarchical Western pitch organization or 'tonality' [7]. For example, adults respond meaningfully to patterns of tension and relaxation, form expectations about the likelihood of future notes, infer that some notes are more prominent than others, and detect 'sour' notes that fall outside of the established scale, key or harmony. Electrophysiological studies reveal that even when listeners are engaged in another task, auditory cortex in both musicians and non-musicians automatically flags unexpected chord sequences, pitch contours and melodic intervals [16–18] (Box 1 discusses melodic interval processing in greater detail). In behavioral experiments, Western adults more readily detect a one-note melodic change that either violates the key or implied harmony within the key of the melody than a change that preserves key and harmony, reflecting implicit knowledge of Western musical conventions [5]. By contrast, eight-month-old infants discriminate all changes above chance levels and equally well, suggesting no knowledge of key membership or harmony [5]. At age 5, North American children more readily detect violations of key than violations of harmony, but by age 6 or 7 they are sensitive to both key and harmony [5,19]. Electrophysiological measures have shown that some harmonic knowledge is present at younger ages [20] and acquisition of more subtle aspects of tonality continues to develop until at least 9–12 years [21]. Interestingly, the degree of universality for each type of structure seems to predict the order of acquisition, with sensitivity to consonance emerging earliest (universal), system-specific knowledge of key membership developing later (scales are found in virtually all cultures but differ in specific composition), and knowledge of harmony observed last (specific to Western music) [5]. In sum, enculturation to pitch structures follows a clear developmental trajectory in which universal aspects are grasped during or before infancy and system-specific aspects are acquired during childhood.

Learning rhythmic structure: from movement to culture-specific metrical structure

Temporal structure is arguably more fundamental to music than pitch structure, because it forms the basis for virtually all social musical behaviors, such as dancing and ensemble performance. Ontogenetically, rhythm discrimination is observed as young as two months of age [6]. When listening to music, listeners tend to infer an underlying regular or 'isochronous' beat that determines, for example, when to tap or dance [22]. When temporal regularity is compromised or disrupted, adults exhibit difficulties in production (i.e. tapping) [23,24] and discrimination [25,26]. Like adults, infants as young as 7 months infer an underlying beat, categorizing rhythms on the basis of meter [22], and 9-month-old infants more readily notice small timing discrepancies in strongly metrical than in non-metrical rhythms [27].

Our sense of rhythm might be based in biological rhythms, such as walking and the heartbeat. This idea is supported by findings of multisensory interactions between movement and auditory rhythm in infants and adults [28,29]. Specifically, when infants are bounced to an ambiguous rhythm (i.e. a rhythm without accents) in either a 'march' pattern (bounced on every second beat) or a 'waltz' pattern (bounced on every third beat), they show a subsequent preference for an auditory-alone version of the rhythm with accents that match how they were bounced (i.e. every second or every third beat), even though they all heard the same ambiguous rhythm during the bouncing. Thus, movement affects how infants interpret an auditory rhythm. Furthermore, the vestibular system, which develops before birth and provides ample input to infants through bouncing, rocking and walking, is crucial to this early-developing interaction, as shown by the finding that rhythmic galvanic stimulation of the vestibular nerve alone biases adults to 'hear' the ambiguous pattern as a waltz or a march [30].

Perhaps because our sense of rhythm originates in regularities of movement, the ratios between lengths of temporal intervals in music typically involve small integers such as 1:2. However, considerable cultural diversity characterizes temporal interval relations in music, with some cultures dividing time intervals into, for example, 11 beats. Western metrical structures contain predominantly simple-integer ratios, such as 1:1 and 2:1, and Western listeners have considerable difficulty perceiving and producing temporal patterns with less regular structures such as 3:2 [23,24,26,31]. Problems arise when adults attempt to encode such patterns according to their culture-specific expectations. For example, Bulgarian and Macedonian adults exposed to Balkan music, which contains ratios consistent with both isochronous (i.e. 2:1 and 1:1) and non-isochronous (i.e. 3:2) meters, are equally good at detecting disruptions to isochronous and non-isochronous meters, whereas adults from North America only succeed with isochronous meters [26].

Enculturation to rhythm and meter begins during infancy; North American infants respond equally to disruptions of Western and Balkan rhythms at 6 months but fail only in the Balkan context by 12 months [26,31], a developmental pattern that is consistent with enculturation processes in other domains, such as musical scale, speech and face perception [5,6,32]. Like enculturation to tonal structures, culture-specific metrical knowledge might continue to develop throughout childhood. For example, studies of synchronized and spontaneous rhythmic tapping suggest that this ability improves and expands to slower tempos from toddlerhood through adulthood [33–35]. These changes might reflect increased culture-specific knowledge of deeper hierarchical metrical levels (and thus longer time spans) [35].

Children probably acquire system-specific knowledge through exposure to the statistics of the music they hear. For example, tonally prominent pitches in Western music occur more frequently and at salient places in music, such as phrase-final or metrically strong positions [22]. Such cues enable adults to infer 'rules' of tonal structure from relatively brief exposure to musical sequences [22,36]. Even 7-month-old infants can associate particular pitches with metrical strength [22], suggesting that such statistics

Box 2. Relations between music and language in development

Music and language are often compared as universal communication systems that both rely on hierarchically organized sound and grammatical rules that govern the sequencing of discrete elements. Recent controversy has surrounded the question of whether musical abilities arise from shared linguistic and musical structures, or from a unique, species-specific cognitive module or 'music faculty' [1,40]. In support of the modular account, some individuals with significant impairment in music (amusics) seem to exhibit no linguistic deficits [40]. However, recent work shows that amusic individuals do, in fact, have difficulty discriminating pitch glides that mimic the prosody of speech [53] and, likewise, individuals with purportedly language-specific disorders have impaired perception and production of musical rhythms [54]. However, if music and speech share processing resources, even though their contents are different, similar brain areas should be activated for music and language. Indeed, studies of non-impaired adults indicate that violations of linguistic and musical syntax activate similar networks in the brain [18,55].

Few would disagree that the contents or elements of speech and music are different. However, in preverbal infants, speech and music are probably less differentiated; indeed, the exaggerated pitch and rhythmic contours of infant-directed speech have led many to adopt the term 'musical speech'. Infants' representations of music and language undergo substantial developmental change, and become increasingly specialized with increasing age and experience. Moreover, music training appears to have cross-domain effects, such as enhancing musicians' sensitivity to prosodic structures in language [56], increasing brain responses to violations of linguistic pitch [45,57,58], as well as syntactic structure [59].

can, in principle, be used to acquire tonal knowledge. Similarly, 12-month-old infants (but not adults) readily learn foreign rhythms after two weeks of at-home exposure to metrical categories in foreign music [31]. Although culture-specific developmental changes have been shown during infancy for rhythm but during childhood for pitch structure, it is unclear whether knowledge of rhythm precedes knowledge of pitch. Future studies using a wider range of ages and testing paradigms might reveal that enculturation processes for rhythm and pitch structures develop in parallel. An interesting possibility is that culture-specific musical development might influence, or be influenced by, acquisition of knowledge in other domains such as language. If culture- and language-specific representations are largely built up from exposure to the statistics of auditory input, then overlap in the sounds

Box 3. Music training and the development of auditory cortex

Anatomical and functional studies suggest substantial effects of musical training on brain development [17,60–63]. Already at the level of the brainstem, evoked responses to sound are larger and more accurate in adult musicians compared with non-musicians [56]. These differences are maintained in auditory cortex for musical tones, with larger evoked responses in musicians than non-musicians [63]. For example, N1m (the first large cortically generated frontally-negative component of the MEG response to sound) is larger in musicians than in non-musicians only for the instrument of practice, strongly suggesting that the effect is owing to experience rather than genetically driven processes [64]. The P2 (second large cortically generated component of the event-related potential or ERP) component is also larger in musicians than in non-musicians [63]. This component, unlike the N1, remains highly neuroplastic in adults and increases in amplitude specifically for stimuli that are trained in the laboratory [65,66]. The musician's brain also shows larger change detection responses (mismatch negativity or MMN) for unexpected changes in single melodies [17], polyphonic melodies [62] and chords [18].

Understanding the childhood origins of the adult musician's brain is complicated by the fact that auditory cortex undergoes a protracted developmental time course. Unlike adults, the ERP responses of young infants are dominated by slow positive waves; by 3 to 4 months of age, faster negative components are apparent in response to unexpected sound features [67,68] (Figure Ia). Using geodesic nets, ERPs can be measured similarly in infants, children and adults (Figure 1b). The N1 and P2 responses to sound described above for adults are so small as to be difficult to observe in children under 4 to 6 years of age. These components increase in amplitude with age, reaching a maximum around 10 to 12 years, and diminish to adult levels by ~18 years [69,70] (Figure Ic). This maturational trajectory fits with anatomical data from autopsy studies showing gradual development of neurofilament in upper cortical layers (II and upper III) between 6 and 12 years, which enables fast, synchronized firing of neurons [71]. Because these layers contain the primary connections to other brain regions and are central to the generation of N1 and P2, protracted development of inter-cortical projections might underlie the development of adult-like brain responses. Interestingly, musical training seems to accelerate this development because 4- to 6-year-old children studying Suzuki music show larger N1 and P2 responses than children not undergoing musical training [69] (Figure Id). In summary, the effects of musical training on networks in auditory cortex can be seen in early childhood.

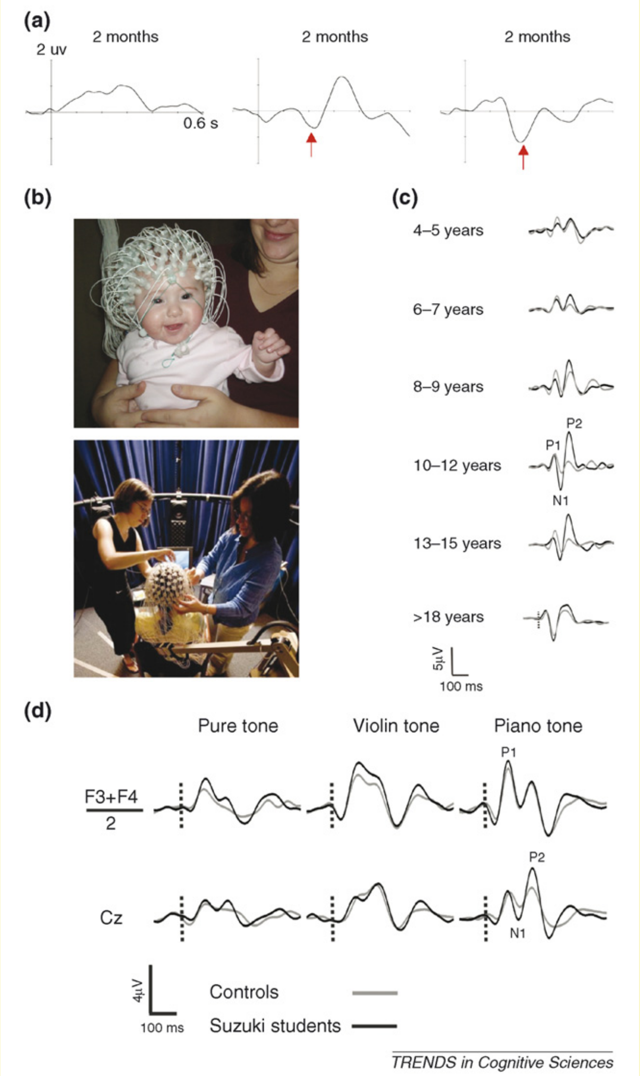

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Figure I. Auditory cortical evoked responses to sound in infants and children. **(a)** Difference waves at a right frontal electrode evoked from a stream of piano tones (evoked response to deviant minus standard tones) showing that responses to pitch change in 2-month-olds involve an increase in a positive slow wave, whereas responses in 3- and 4-month-olds involve a negative component (shown by arrows) peaking around 210 to 230 ms after sound onset resembling the adult mismatch negativity (MMN) component. This component is larger and earlier at 4 months compared with at 3 months, although not yet at adult values. The *x*-axis marks the onset of the tones (data replotted from Ref.[68]). The *y*-axis shows response amplitude in microvolts (uv). **(b)** Illustrations of the geodesic nets used to record the evoked responses. **(c)** Evoked responses to 500 ms piano tones (inter-stimulus interval 2500 ms) in children from 4 years of age to adulthood from frontocentral (average of F3 and F4, light line) and central (Cz, dark line) sites. N1 and P2 responses continue to develop until age 18 (data republished, pending permission, from Ref. [69]). **(d)** N1 and P2 responses to the piano tones described for (c) are larger in 4- and 5-year-old children taking Suzuki music lessons in comparison to those not taking lessons (data republished with permission from Ref. [69]).

of speech and music might fundamentally shape representations early in life. Indeed, characteristic rhythmic and pitch structures of spoken languages have also been observed in the musical rhythm and pitch structures from the corresponding culture [37–39]. Future studies might examine whether these speech–music similarities exist in children's music, and whether cross-domain influences between music and speech can be observed during development (see Box 2 for further discussion of links between music and language).

In summary, for both pitch and rhythmic aspects of music, infants are sensitive to basic universal features – consonance and metrical interpretation based on movement – which provide the scaffolding for building complex, culturally unique musical systems. This sensitivity, in turn, provides the base from which infants can learn the complex musical structure of their own culture.

Formal musical experience

Virtually all members of society acquire implicit culture-specific knowledge of the spectral and temporal structure of music, but there is a wide range of musical experience and expertise, with some individuals practicing and performing music for many hours a day over the course of many years. An increasing number of studies suggest that music lessons profoundly influence the developing brain, making music training a promising model for examining learning, brain plasticity and critical periods [5] (Box 3). Although it is clear that extensive music training in childhood affects development, controversy surrounds the question of whether such effects are specific to music or extend to other domains. Modular accounts describe music as independent from other domains, and that particular aspects of music, such as pitch and rhythm, are informationally encapsulated [40]. By contrast, musical training or musical ability is correlated with performance on a wide variety of cognitive tasks, including pre-reading and reading ability, and mathematical and spatial abilities [41,42].

Evidence is mounting that formal musical training has both domain-specific and domain-general effects on development. Although much excitement was generated by initial reports of enhanced spatial reasoning after passive listening to Mozart, subsequent research shows the so-called 'Mozart effect' to be of short duration (minutes) and dependent on modulation of arousal and mood [42]. Indeed, even upbeat rock music can improve performance more than slow classical music [42]. In general, studies of musical learning are consistent with the animal literature indicating greater plastic changes in the brain for behaviorally relevant (e.g. association with reward) than for passive exposure to auditory stimuli [43].

Studies of 'transfer' between music training and tasks in other cognitive domains typically use correlational methods, making it impossible to distinguish musical training effects from innate musical ability [41,42]. However, in one study, 6-year-old children were randomly assigned to one year of music lessons or drama lessons, and IQ was measured before and after training [44]. IQ in children taking music lessons improved more than children taking drama lessons. Moreover, modest but consistent gains were made across all four indexes of the IQ, including verbal comprehension, perceptual organization, freedom from distractibility and processing speed, suggesting that music training has widespread domain-general effects. Two longitudinal brain-based studies have followed children taking and not taking lessons [45,46]. Interestingly, the largest group differences were found for later components, reflecting general cognitive processes, whereas only modest differences were observed in the earlier components reflecting perceptual processes. For example, eight weeks of musical training in 8-year-olds was associated with a decreased late positive event-related potential (ERP) to incongruous prosody [45], reflecting greater ease of processing and lower attentional requirements after music training. Likewise, four magnetoencephalography (MEG) measurements taken in 4- to 6-year-old children over the course of a year (half of the children were taking Suzuki music lessons and half were not training musically) revealed a greater decrease over time in the size of a component associated with attentional processing in the music group compared with the non-music group [46]. Thus, small but widespread effects of musical training on cognitive processing might occur because music lessons train attentional and executive functioning, which benefits almost all cognitive tasks. Perhaps the demands of listening to and remembering the sounds of the teacher, monitoring and consciously controlling the motor system to modify one's own sound, and learning to inhibit behavior when synchronizing with others, all contribute to enhanced executive functioning across multiple domains.

Conclusions

Musically trained and untrained adults alike process music using perceptual and cognitive networks set up through experience. Throughout development, these networks become increasingly specialized for encoding the musical structure of a particular culture. Certain universal aspects of musical structure, such as the preference for consonance over dissonance, are found early in development and probably arise from properties of the basilar membrane and auditory nerve, in conjunction with general exposure to spectrotemporally structured sounds. This early sensitivity might set-up the scaffolding for learning scales and harmony, which, in turn, form the basis for a specific musical system, such as Western tonality. Likewise, the early perception of metrical structure might arise through the presence of connections between movement and auditory areas of the nervous system in conjunction with everyday correlated multisensory experiences with sound and movement. Formal musical instruction seems to train a set of attentional and executive functions, which have domain-specific and domain-general consequences (Figure 1). The developmental process is complex. Plasticity is affected by various anatomical processes, such as synaptic proliferation and pruning, myelination, and neurofilament and neurotransmitter levels, each of which has its own developmental trajectory. Plasticity is also reduced with learning as neural networks settle into more stable states. In the face of this complexity, it remains for future research to determine the precise effects of different kinds of musical experience at different ages.

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