FEATURED ARTICLE

How Early Music Training Changes the Brain

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Recent decades have witnessed significant advancements in research that aid in our understanding about how the human brain develops the ability to process the dynamic and complex acoustics of music (Loui and Belden, 2019; Russo, 2020). One particular question, Whether having music training early in life can have an impact on the development of the human brain?, has intrigued not only scientists but also parents, educators, and policymakers. As this article demonstrates, we now have a good body of evidence supporting this idea and that the effect of music training may be particularly valuable for young children.

The effect of music training on the brain is a critical scientific question to pose from both a theoretical and an application point of view. From the theoretical perspective, studying early music training provides an excellent model for studying neural plasticity in humans, that is, how the brain changes in response to environmental changes (Herholz and Zatorre, 2012). Thanks to advancements in neuroimaging methods (e.g., magnetic resonance imaging [MRI], magneto- [MEG]/electroencephalography [EEG]; see Loui and Belden, 2019, for a brief introduction), we can now examine changes in the brain noninvasively, in both their structure and functions. Several theoretical frameworks have been proposed to guide our investigation as to what and how changes take place in the brain as a result of early music training (Kraus and Chandrasekaran, 2010; Patel, 2014). The majority of this review focuses on the structural and functional changes in the brain related to early music training, both within and beyond the realm of music processing.

From the application perspective, understanding how early music training can affect brain development could have important implications for children with or at risk for clinical diagnoses of communication disorders. For example, converging evidence has shown that early music training can benefit speech processing, raising the question of whether we can leverage music training in the future as an alternative treatment approach for developmental communication disorders. We review emerging clinical studies focusing on the effects of early music training on children at risk for or with dyslexia. Taken together, this review harnesses considerable evidence suggesting that early music training affects brain development, and further investigation in this area is needed to enhance both theory and clinical practice.

Defining Early Music Training

To understand the effects stemming from early music training, it is important to first define (1) what should be considered as "early" and (2) what should be considered as music training. The concept of early comes from research showing "critical periods" for general human learning. For example, in language learning, it has been observed repeatedly that the overall ability to acquire a second language starts to decline significantly after 7 years of age, making the period before age 7 critical and early for language learning (Kuhl, 2010). So far, music research has largely adopted the same time frame from language research, and, indeed, interesting parallels have been observed between the time lines for music and language learning (e.g., Hannon and Trehub, 2005a,b; discussed in detail in ***Music Exposure***).

Second, for an experience to be considered as music training, it needs to involve active participation in a musical activity for a prolonged period of time. This is in contrast to two other commonly discussed key concepts: music exposure and music aptitude. Human brains can learn a lot about the surrounding environment without even paying attention to it (i.e., passive exposure), and this ability is much stronger in infants and children than it is in adults. For example, six-month-old infants can learn to differentiate new speech sounds with only two minutes of exposure (Maye et al., 2002). At the same time, there is also great intrinsic variability across individuals in this ability to learn information from passive exposure.

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We briefly discuss the literature on music exposure and music aptitude before moving forward to examining music training.

Music Exposure

Humans begin to experience music (as well as speech) even before birth (Birnholz and Benacerraf, 1983). Passive exposure to a musical environment, such as a fetus hearing its mother sing, is a crucial way through which people learn music and become more proficient in processing music from their culture (Bigand and Poulin-Charronnat, 2006). Music from different cultures can be very different. For example, Western music equally divides an octave (i.e., doubling the fundamental frequency) into 12 intervals, whereas Turkish music equally divides an octave into 53 intervals. Demorest and colleagues (2008) demonstrated that when adult participants without musical training from the United States and Turkey heard novel music excerpts from both Western and Turkish cultures, all of participants were significantly better at later recognizing music excerpts from their own culture than the unfamiliar culture.

Learning music through passive exposure starts in infancy. Hannon and Trehub (2005a,b) played music excerpts with rhythms of Western culture and of Balkan culture (e.g., Northern Macedonia to a group of infants from North America raised in Western music culture). Some of the excerpts contained disruptions to the rhythm. The researchers observed that although 6-month-old infants can detect these disruptions in both Western and Balkan music excerpts, 12-month-old infants can no longer do that for the Balkan music. This demonstrates that infants are learning music characteristics specific to their culture at a very early age, similar to when they start learning speech sounds of their native language (Kuhl, 2010). Yet, when another group of North American infants had Balkan regional folk music played in the background at home between 6 and 12 months of age, these infants maintained their ability to process the Balkan rhythms at 12 months.

Music Aptitude

Individuals' ability to process music varies widely. Although the amount of passive exposure may contribute to this variance, the variance is largely attributable to inherent individual differences such as genetic predisposition. Music aptitude is a widely used term to characterize this intrinsic individual variability in auditory skills and an individual's potential to achieve in music.

One of the most commonly used standardized tests to measure music aptitude is the Advanced Measures of Music Audiation (AMMA), developed by Gordon (1989). The AMMA measures music processing in various areas including acoustic features such as pitch and duration as well as structural composition such as chord progression and meter. Studies have reported a relationship between music aptitude and speech processing within nonmusicians, shedding light on the shared mechanisms between music and speech processing. In one study, an adult's neural discrimination of speech stress patterns, for example, PERfect (adj.) vs. perFECT (verb.), measured by an EEG, was found to be significantly correlated with his/her music aptitude score as measured by the rhythm subset of AMMA (Magne et al., 2016). These results led to the suggestion of a generalized rhythm processing skill that underlies both music and speech.

Early Music Training

Although intrinsic variation exists across individuals in their ability to process music and many aspects of these skills can be learned and shaped through passive exposure to music, we now turn the discussion to the active early music training that can cause additional changes in neural structures and functions, both within the domain of music processing and in domains outside of music processing, such as speech processing and cognitive skills. When changes occur beyond music processing, researchers have named them "transfer effects" (Besson et al., 2011).

Effects of Early Music Training?

Cross-Sectional Research and Longitudinal Research

The first type of studies that researchers conducted to examine the effect of early music training is called cross-sectional studies. Specifically, cross-sectional studies compare groups of individuals with distinct music training backgrounds and examine how their brains are different. Cross-sectional studies impose highly selective rules to ensure that participants' music training backgrounds are sufficiently different to allow any group differences to be detected. For example, it is common in studies to define adult "musicians" as people who have had more than eight years of continuous private lessons that started before age seven, while "nonmusicians" cannot receive more than one year of formal music training anytime in their lives. A second type of study that researchers later adopted is called longitudinal studies, in which researchers follow a group of people as they begin to engage in music training for a period of time and observe changes in their brain compared with a group of controls who do not engage in music learning.

Most studies in the literature belong to these two categories, and we now review them in detail. From cross-sectional and longitudinal studies, three areas of neural differences emerged between trained and nontrained individuals, namely, neural structure, neural function in processing music, and neural function beyond music processing.

Neural Structural Differences

Researchers have found differences between musicians and nonmusicians in the structures of the brain. The differences have been observed in both the cortical gray matter and white matter characteristics. The gray matter of the cortex mainly consists of cell bodies. Specific brain functions, such as sound processing, are considered to be related to the gray matter characteristics in specific brain regions, such as the auditory cortex. One main characteristic of the gray matter is its volume or how much gray matter there is. Gaser and Schlaug (2003) examined the gray matter volume across all brain regions using MRI technology in three groups of participants: nonmusicians, amateur musicians, and professional musicians. Although both professional and amateur musicians satisfied the selection criteria for musicians, professional musicians further satisfied criteria that they were music performers or teachers who practiced for at least one hour a day while amateur musicians were people who played regularly but worked in fields outside of music. Researchers found gray matter volume differences across the three groups of participants in three cortical areas: auditory, motor, and frontal regions (**Figure 1**). Specifically, professional musicians had the largest gray matter volume, whereas nonmusicians had the smallest volume in these regions. The differences observed support the idea that music learning involves strenuous motor practice in addition to hearing and that this may result in bigger volumes in motor related regions. In fact, Bangert and Schlaug (2006) later found that professional musicians had increased gray matter volumes in the cortical regions specifically related to hand function. Moreover, pianists showed a larger volume for the right hand while violinists showed a larger volume for the left hand, reflecting the differences in the hand dominance in playing these instruments.

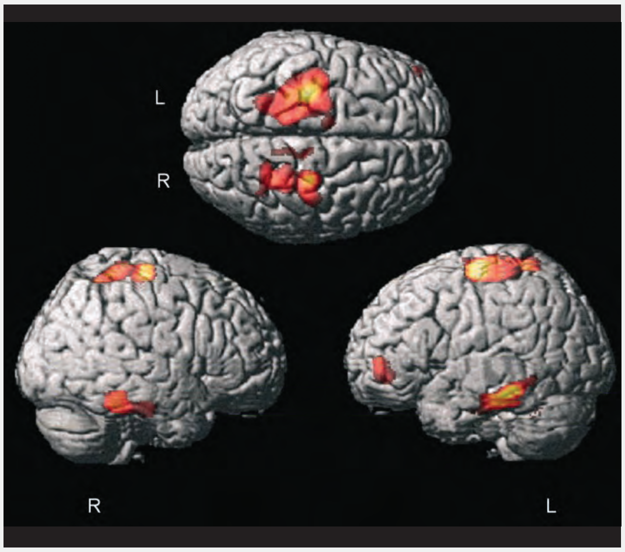


Figure 1. *Reconstructed cortical surface of a human brain from raw magnetic resonance imaging (MRI).* ***Top:*** *top of the brain with front of the head to the* ***right****.* ***Bottom:*** *right (R) and left (L) sides of the brain with the front of the head toward the* ***center****. The* ***colored areas*** *on the cortical surface indicate that there is a significant relationship between the gray matter volume of that region and an individual's music training background. The brighter the color, the more robust the relationship. These regions are within the boundaries of the auditory, motor, and frontal cortices. Adapted from Gaser and Schlaug, 2003, with permission; copyright 2003 Society for Neuroscience.*

On the other hand, cortical white matter generally consists of axons of neurons and its characteristics, such as the amount of white matter and the alignment of axons, generally reflect the "interconnection" or "communication" across regions of the brain. For example, more white matter and better axon alignment support faster communication across brain regions. Bengtsson and colleagues (2005) compared a group of professional concert pianists with age-matched nonmusician controls in terms of their cortical white matter characteristics. The investigators found differences between the two groups in the axon alignment in the major pathways that connect the left and the right sides of brain, the frontal and the temporal regions of the brain, and the brain and the spine. More importantly, the more time the individual had spent in childhood practicing piano, the better the white matter axons align with one another, thereby providing better infrastructure for faster communication across brain regions.

These results were replicated when researchers followed a group of children for up to 29 months and compared children who started music training between 5 and 7 years of age with controls who did not receive any music training during this period. Significantly, structural differences between the two groups only started to emerge after 15 months of training, speaking to the idea that structural changes in the brain require prolonged, intensive training (Hyde et al., 2009).

Functional Differences in Music Processing

The first questions researchers examined regarding functions involved how musicians' brains responded to different elements of music in comparison to the brains of nonmusicians. In a series of studies, Pantev and colleagues (1998, 2001) demonstrated that musicians, compared with nonmusicians, exhibited stronger neural activity in the brain in response to musical sounds, especially if the spectral profile is similar to that of their primary instrument. For example, trumpeters responded to musical sounds made by trumpets more than to musical sounds made by violins, and vice versa for the violinists. In addition, researchers also observed that musicians detected pitch changes better than nonmusicians but only when the pitch changes were embedded in a context, such as intervals, chords, and melodies (Koelsch et al., 1999; Fujioka et al., 2004). Longitudinal studies following children starting to take violin lessons also showed similar effects in sound processing. For example, after a year of violin lesions, musically trained children demonstrated stronger neural activation for violin sounds than nontrained children but not for white noise (Fujioka et al., 2006).

Quite a few studies have also examined differences between musicians and nonmusicians in the neural processing of musical rhythm. Most studies focused on two hierarchical levels of musical rhythm: the beat-level rhythm that gives a regular pulse like a metronome and the meter-level rhythm that further groups the regular beats into patterns, such as strong-weak-strong-weak in a marching rhythm (Fitch, 2013). In earlier studies, rhythm processing was largely examined by measuring the neural response to the disruptions of a regular rhythm, with a larger response indexing better detection of the disruption. From better detection of disruption, we can infer better tracking of rhythm (Zhao et al., 2017).

Using the same approach as above, researchers manipulated music excerpts to contain occasional disruptions that either disrupt the beat-level rhythm or the meter-level rhythm. To illustrate, imagine a waltz rhythm with three beats equally spaced in a group, strong-weak-weak. A beat-level disruption would move the last weak beat closer to the middle weak beat and farther from the next stronger beat. A meter-level disruption would eliminate the last weak such that it becomes strong-weak-strong-weak-weak. When musicians' and nonmusicians' neural responses to these disruptions were measured, researchers showed that the two groups can detect beat-level rhythm disruptions equally well, whereas musicians can detect meter-level disruptions much better (Vuust et al., 2005; Geiser et al., 2010).

In the last few years, a new approach has been developed to allow direct measurements of neural tracking of beat- and meter-level rhythms without the occasional disruptions. Using this approach, a recent study showed that musicians' neural tracking of beat- and meter-level rhythms were both enhanced. Furthermore, how well the neural signal tracks rhythm is correlated with years of training, suggesting a music training related effect (Doelling and Poeppel, 2015).

Functional Differences in Speech Processing: Evidence for Near-Transfer Effects

Speech processing is considered closely related to music processing because of the similar characteristics of the two acoustic signals and their common ubiquitous nature in the world's cultures. Whether early music training can generalize its effect to speech processing, which is called the near-transfer effect, became a heavily studied question because speech processing is crucial to human communication. Over the years, converging evidence has shown that early music training indeed affects speech processing (Patel, 2014).

Researchers first approached the "near-transfer effect" question by examining how musicians and nonmusicians process pitch information in speech. Various studies quickly demonstrated converging results showing more advanced pitch processing for native speech in musically trained individuals (adults and children), such as detecting pitch changes in syllables as well as at the sentence level (Schon et al., 2004; Chobert et al., 2011). More strikingly, musicians were also able to process pitch variations in foreign speech sounds much better than nonmusicians. Tonal languages, such as Mandarin, provided an ideal window to examine this question as the pitch variation patterns (e.g., lexical tones) at the syllable level indicate word meaning. For example, in Mandarin, there are four different types of lexical tones: ma in Tone 1 (level pitch) means "mom," whereas ma in Tone 4 (dropping pitch) means "scold." To date, nontonal language-speaking musicians have exhibited an enhanced ability in processing and discriminating lexical tones behaviorally and neurally at the cortex and even at the subcortical brainstem (Wong et al., 2007; Marie et al., 2011a; Zhao and Kuhl, 2015).

Very few studies have examined differences in speech rhythm processing between musicians and nonmusicians and the results are mixed. On the one hand, it was found that musicians were better able to detect occasional shortened vowels when the vowels were played repeatedly, both behaviorally and in the cortex (Chobert et al., 2011). In addition, when the relationships between syllable durations in words were manipulated in a sentence, such as "mama" with equal duration for both syllables changed to longer duration for the first syllable, musicians exhibited higher sensitivity to such manipulations (Marie et al., 2011b). On the other hand, when examining how the neural signal follows the amplitude modulation patterns in music and speech signals, Harding and colleagues (2019) found a musician advantage in tracking the music rhythm but not in the speech rhythm. Given the mixed results, more studies are warranted for us to elucidate the effects of early music learning on speech rhythm processing.

Functional Differences in Other Domains: Evidence for Far-Transfer Effects

Limited research efforts have also been devoted to examining whether the "transfer effect" from early music training generalizes beyond speech processing to more general domains that are not as closely related to music processing, such as memory and attention skills (i.e., far transfer). The results from these studies are mixed, and the question regarding "far transfer" remains highly debated. For example, Chan and colleagues (1998) first observed that musically trained adults and children recalled, both immediately and after some delay, a significantly higher number of words from a list read to them compared with nontrained individuals. This original study was done with a Cantonese-speaking population using the Hong Kong Verbal Learning Test and the effects were later replicated using the California Verbal Learning Test-II with English-speaking musicians and nonmusicians (Jakobson et al., 2008). Strait and colleagues (2010) tested a group of musicians and nonmusicians on a series of different tasks that targeted both cognitive abilities such as auditory working memory (reverse digit recall) and auditory attention (detection of a "beep" while watching a video). The results demonstrated better performance by musicians on auditory attention but not on auditory working memory.

By contrast, George and Coch (2011) observed enhanced working memory in musicians by conducting a more comprehensive set of standardized tests. Indeed, much more work is needed to examine these far-transfer effects, and only with more experimental results can we start to understand the whole picture of effects of early music training on general cognition.

Randomized Controlled Studies

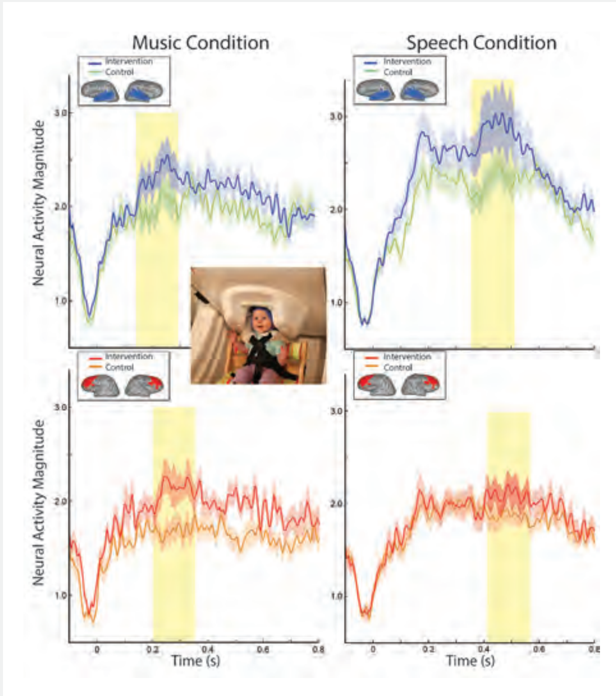
As the results from cross-sectional and longitudinal studies start to converge, it becomes critical to address one outstanding issue in these studies, genetic predisposition. Indeed, musicians could be genetically predisposed to have better auditory skills, which might have prompted them to seek more musical activity and training early in life. The key to addressing this issue is by conducting randomized controlled intervention studies. By randomly assigning participants to receive either music training or a control activity for a period of time in a controlled manner, we can measure with confidence whether any differences in outcome measures are due to the music training rather than genetic predispositions.

Here, we review the few existing randomized controlled experiments in more detail. A few studies have focused on school-age children. Moreno and colleagues (2009) randomly assigned nonmusically trained 8-year-old children to attend 24 weeks of either a music or a painting class. Both before and after the training period, a series of tests assessed the children's pitch processing in music and speech, reading skills, general intelligence, and memory abilities. The results demonstrated that children who received music training exhibited better pitch processing in music and in speech. Furthermore, musically trained children exhibited a significant decrease in the error rate in the reading skill task. However, no differences were observed in verbal and working memory tasks between the two training groups.

Moreno and colleagues (2011) conducted a second study on four- to six-year-old children focusing only on addressing the question of far-transfer effects (i.e., effects on general cognitive skills) with a shorter 4-week training protocol. Vocabulary and executive functioning, such as the ability to inhibit distraction and switch attention, were used as measures. Moreno and colleagues found that only children with music training showed significant increases in vocabulary and performance on the executive function tasks, providing a strong argument for the far-transfer effects. Kraus and her colleagues (2014) designed a study that randomly assigned eight-year-old children into two groups. One group started an after-school music curriculum immediately after enrollment to the study while the other group started the same curriculum one year after enrollment in the study. Children's auditory brainstem encoding of speech was measured repeatedly over the next few years. No difference was observed after the first year of the study, but after two years, the group with two years of training exhibited better encoding of speech than the group with only one year of training, suggesting the effect at the auditory brainstem takes prolonged training to manifest.

Following the previous studies with children, we examined whether a short-term randomized controlled music intervention can affect infants' neural processing of both music and speech (Zhao and Kuhl, 2016). Nine-month-old infants were randomly assigned to complete a 12-session laboratory-controlled music intervention or free play over a month period. The music intervention was social in nature, where groups of infants engaged in rhythmic activities such as clapping hands to musical beats with their caregivers. The control group engaged in everyday play activities, such as stacking building blocks, in the same environment but without music. The infants' neural processing of music as well as speech rhythm was measured after one month. Indeed, infants who completed the music intervention demonstrated better processing of both music rhythm and speech rhythm, demonstrating a transfer effect in infants as young as nine months of age (**Figure 2**). More importantly, using MEG, we were able to examine these effects in specific regions of the cortex. We again found that, in addition to the auditory region that is generally considered to be responsible for sound processing, enhanced neural activities were also observed in the prefrontal regions, generally considered be responsible for higher cognitive skills, such as inhibitory and attentional control. This result was in line with our hypothesis that a higher level skill shared

Figure 2. *Infants in both the intervention and control groups were measured in the magentoencephalography (MEG) machine after completing all intervention/play sessions (**center inset**). Their neural responses to occasional disruptions to music rhythm (**left**) and speech rhythm (**right**) are shown. The onset of the sound happens at time 0. **Yellow bars:** time window where the response to the disruptions are expected to happen. **Top:** neural responses in the auditory region (**blue regions** on the brain). **Bottom:** neural responses in the prefrontal region (**red regions** on the brain). Infants in the music intervention group showed enhanced responses in the auditory cortex (**blue lines**) as well as in the prefrontal region (**red lines**) compared with the control group (green and orange lines) for processing both music and speech rhythms.*



by music and speech processing, namely, temporal pattern recognition and error detection, is strengthened by the music intervention. Still, future research is needed to examine directly whether higher cognitive skills would, in fact, be affected by infant music intervention.

Clinical Application/Treatment Studies

One of the long-term goals for understanding the effects of early music training lies in the application for clinical populations. As we start to understand the underlying mechanisms supporting the transfer effects from early music training to speech processing and general cognitive abilities, we can start leveraging music as an alternative early intervention method to treat developmental communication disorders. New applied intervention studies have emerged in the last few years. For example, a group of children between 8 and 11 years with a diagnosis of dyslexia were randomly assigned to a 30-week-long music intervention versus conventional treatment. While both groups improved, the music intervention group outperformed the control group in several key measures, including reading accuracy, phonological awareness, and rhythmic abilities (Flaugnacco et al., 2015).

Virtala and Partanan (2018) reported an on-going intervention with infants at risk for dyslexia. At-risk infants were randomly assigned to vocal music intervention, passive instrumental music listening intervention, and no intervention at birth. The intervention lasts for 6 months and the infants' neural processing of speech sounds were measured at 6 months and will again be measured at 2.5 years, along with comprehensive neurological tests. Preliminary results from 6-month-old infants already shows that their neural responses to sounds and communicative skills are related to the amount of music intervention the infants are receiving. Complete results from such studies will open new directions in research that address the efficacy of music intervention to ameliorate early communication disorders.

Summary

To summarize, we reviewed a considerable amount of evidence supporting the idea that early music training affects brain development. Ongoing research continues to elucidate the mechanisms underlying these effects. For example, what are the most important elements in music training to generate the transfer effects? What is the extent to which music training can affect brain development, for example, can it affect math skills (Vaughn, 2000)? Furthermore, the potential importance of music training for clinical populations with communication disorders is also emerging through new clinical studies. Are the effects from music training observed from typically developing children the same for children with/at-risk for communication disorders? Would certain types of music intervention, such as singing, be more effective as a treatment? Indeed, these new directions make the study of music intervention in clinical populations one of the new frontiers in the science of music and its effects on the brain.

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