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Music training and speech perception: a gene–environment interaction

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Claims of beneficial side effects of music training are made for many different abilities, including verbal and visuospatial abilities, executive functions, working memory, IQ, and speech perception in particular. Such claims assume that music training causes the associations even though children who take music lessons are likely to differ from other children in music aptitude, which is associated with many aspects of speech perception. Music training in childhood is also associated with cognitive, personality, and demographic variables, and it is well established that IQ and personality are determined largely by genetics. Recent evidence also indicates that the role of genetics in music aptitude and music achievement is much larger than previously thought. In short, music training is an ideal model for the study of gene–environment interactions but far less appropriate as a model for the study of plasticity. Children seek out environments, including those with music lessons, that are consistent with their predispositions; such environments exaggerate preexisting individual differences.

Keywords: music training; speech; intelligence; aptitude; personality; perception

Introduction

Do music lessons cause improvements in nonmusical perceptual or cognitive abilities? The question is not easy to answer definitively because assigning individuals at random to music lessons for substantial durations of time is difficult, costly, and prone to problems of attrition. Nevertheless, researchers frequently infer from correlational data that music lessons cause improvements in visuospatial abilities, memory, and language-related abilities such as speech perception, reading, and vocabulary. The goal of the present article is to challenge these assumptions by focusing on studies of speech perception. The argument is that preexisting differences influence who takes music lessons, such that even if music lessons do indeed cause changes in behavior and brain structure and function, this is only part of the story.[1] Rather, genes determine music aptitude, personality, and cognitive abilities, which, in turn, play a major role in determining social status and the likelihood of taking music lessons. In short, contrary to popular belief,[2,3] music training is a poor model for the study of plasticity (i.e., the ability to change in response to environmental influences), but an excellent model for the study of interactions between genes and the environment.

This review focuses solely on original research or reviews published from 2009 onward, with four exceptions from earlier years that are used to highlight the historical context. Before beginning a discussion of speech perception, I provide a brief review of associations between music training and other cognitive abilities, which are discussed in detail elsewhere.[4] Correlational evidence confirms that positive associations between music training and language abilities (e.g., reading and spelling) can be evident even when IQ is held constant.[5,6] Moreover, experimental evidence points to increases in visuospatial abilities, reading abilities, and IQ as a function of music training.[7–9] Even short-term (4 weeks) computerized training can cause increases in vocabulary, selective attention, and prereading skills.[10,11]

Nevertheless, it is unreasonable to infer from correlational data that music training causes the large differences reported in cognitive abilities between

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musically trained and untrained children[5,12–14] or the differences in academic achievement[15–17] or personality.[16] Rather, nonmusical associations with music training that are evident in the real world must be a consequence of genes and the environment, and of interactions between genes and the environment. High-functioning children who are open to experience, conscientious, and from high–socioeconomic status (SES) families are more likely than other children to take music lessons,[16] which exaggerate preexisting differences. Inferring causation from correlational data assumes that musically trained and untrained individuals did not differ systematically before the lessons began.[18–23]

Regarding the question of associations between music training and speech perception, there is no doubt that such associations are reliable. Behavioral and neurological studies confirm that music training predicts better perception of pitch or metric incongruities in speech[9,24] and that musicians are better than nonmusicians at perceiving speech in noise.[25–29] Although one study failed to replicate the speech-in-noise effect,[30] another study found the advantage among preschoolers with minimal training.[31] English, French, and Italian musicians also outperform nonmusicians at discriminating lexical tone in Cantonese or Mandarin.[32–35]

Performance advantages associated with music training extend to tasks that require participants to judge whether a sentence's final word is pronounced correctly[36] or to identify the emotions conveyed by an infant's cry or by prosody in speech.[37,38] Even 9-year-olds with 4 years of music lessons are better than their untrained counterparts at discriminating syllables that vary in pitch or duration.[39] Musically trained individuals also exhibit processing advantages for aspects of speech that have no obvious counterpart in music. For example, music training predicts enhanced sensitivity to phonemic contrasts, whether such sensitivity is measured as preschoolers' brain-stem responses[40] or adults' discrimination abilities.[34,41] Other findings show that (1) musically trained deaf children (with hearing aids or cochlear implants) have enhanced performance on tests that require them to discriminate phonemes or to segregate auditory streams;[42] (2) Indian children with music training have better comprehension of spoken English whether they are trained in Western or Indian classical music;[43] (3) adult musicians exhibit advantages at perceiving speech that has been degraded spectrally;[44] and (4) string players have enhanced preattentive neural encoding of vowels that vary in frequency, duration, formant transition, or voice-onset time.[45]

Associations between music training and speech perception appear to be a consequence of enhanced auditory perception in general. For example, music training is associated positively with performance on tests that require listeners to detect small changes in pitch or duration of nonspeech stimuli[36,45–48] or to determine the pitch direction (low-high or high-low) of pure tones presented very briefly.[46,47] Among third-graders, signs of poor auditory perception and memory are common among musically untrained children but notably absent among children with music lessons.[49] Moreover, adults who took music lessons as children continue to exhibit stronger than normal brain-stem responses to sound many years later.[50] Detrimental effects of backward masking are also attenuated among musicians.[27] It is important to clarify that musicians' advantages on tests of central auditory processing (e.g., gap detection, speech in noise) are independent of hearing sensitivity.[29]

In other words, musically trained individuals do not have particularly good hearing, but they tend to be very good listeners, which translates to good speech-perception abilities. In the results described above, however, all of the evidence was correlational except for a single study that assigned 8-year-olds randomly to either music or painting lessons.[9] After 6 months, the music group showed greater improvement than the control group at detecting small pitch changes in speech. In a follow-up study, 8-year-olds were assigned randomly to 2 years of music or painting training.[51,52] After 1 year, the music group exhibited larger increases in electrophysiological responding to syllables that differed in voice-onset time or duration.[51] After 2 years, the music group performed better on a statistical learning task that required them to segment sung nonsense syllables.[52] In the latter case, the use of pitch cues at exposure was likely to facilitate encoding preferentially for the music group, even though items at test were spoken rather than sung. A different research team assigned 8-year-olds randomly to a community-based music intervention at different time points.[53] Children with 2 years of training had larger brain-stem responses to a phonemic contrast (/ba/ versus /ga/) compared to children with only 1 year, but the effect was small. Another recent study found that random assignment of 4- to 6-year-olds to a 4-week training program in music listening caused long-term reductions in electroencephalographic responses to a repeating vowel that changed from /u/ to /y/ (or vice versa), but there were no behavioral measures.[54]

In short, evidence that music training *causes* increases in speech perception is sparse and weak. In the five experimental studies noted above, the advantage was *musical* in nature[9,52] or not reported for actual behavior.[51,53,54] In contrast, associations in correlational studies are consistent across laboratories and strong. On the one hand, it seems eminently reasonable that music lessons make you a better listener in general, and a better perceiver of speech in particular, as theorists predict.[3,55–57] On the other hand, even if music training improves the perception of speech, it does not rule out the possibility that genetic influences could be stronger, weaker, or identical to those of music training.

In fact, speech perception, musical achievement, and basic auditory functions are all associated with music aptitude (hereafter referred to as aptitude). Aptitude refers to natural musical ability—the potential for someone to succeed at music training and/or become a musician. Aptitude is more or less synonymous with talent, although talent requires some sort of behavioral manifestation and is by definition rare, whereas aptitude refers to hypothetical potential that varies continuously—and presumably normally—among individuals. Debates about aptitude include how to measure it appropriately (at the practical level) and whether it even exists (at the conceptual level). Historically, aptitude tests had poor reliability and validity, which weakened their practical value.[58] At the conceptual level, innateness was often associated with biological determinism more generally, which evoked unsavory concepts such as social class and racism.[59,60] In fact, the joke about musical success (How do you get to Carnegie Hall? Practice, practice, practice) became scientific wisdom before the turn of the century. This view posited that such success was the consequence of practice and environmental factors such as parental support, good teachers, and individual differences in motivation.[61,62] Motivation is biological in part but clearly distinct from aptitude or talent.

Aptitude has had a renaissance in recent years as it became clear that genes make a substantial contribution to cognitive abilities, personality, and psychological and physical health.[63] In fact, in many studies, the shared environment—that which siblings growing up in the same home share—makes little or no contribution, leaving the variance unexplained by genes to the unshared environment—that which is unique to an individual and difficult to study systematically. For example, genetic makeup explains about half of the variation in reading performance, whereas growing up in the same home and attending the same schools explains one-fifth.[64] In a study of 4-year-old children's ability to draw a human figure, the results revealed that (1) genes exerted a stronger influence than shared environment on drawing; (2) genes contributed to drawing as much as they did to IQ; and (3) drawing ability at age 4 years predicted IQ at age 14.[65] In the case of music, amusia represents a complete lack of aptitude, at least for pitch. Amusia has been documented thoroughly, diagnosed reliably, and appears to be genetic in origin.[66] If poor aptitude is genetically determined, then good aptitude likely will be as well.

Over the past few years new tests of aptitude have emerged, with improved psychometric properties.[58,67,68] Meanwhile, behavioral geneticists became interested in musical ability and the relative roles of genes and the environment in predicting aptitude and music achievement.[69] As it turns out, the role of practice in determining musical achievement has been overestimated, and aptitude and achievement have a substantial genetic component.[70–75] Although practice may be crucial for truly expert performers,[76] it is less important for the rest of us. For example, people with higher levels of aptitude also practice more than other individuals, but the genetic contribution to deliberate practice is around 70% for males and 40% for females.[77] Thus, even if practice were the driving force behind musical achievement, it would represent a gene–environment interaction. In a sample of 800 twins, the genetic contribution to practice explained about one-quarter of the genetic contribution to music achievement, which implicates genetic contributions to achievement other than practice, such as aptitude.[70] The genetic contribution to achievement is particularly pronounced for individuals who practice frequently, another interaction between genes and the environment.[70]

Linkage studies reveal that some of the genes that determine aptitude are the same as those that determine basic auditory perception,[78] which is in line with behavioral findings revealing that aptitude is associated negatively with gap detection, frequency discrimination, pitch pattern perception, and duration pattern perception.[79] Active listening to music (e.g., going to concerts) is linked to a different set of genes, specifically those that influence attachment and social communication.[80]

Thus, musicians are born as much as they are made, and music aptitude, like music training, is associated with basic auditory skills. As one would expect, then, music aptitude also predicts speech-perception abilities such as nonnative language abilities,[81] but this association is at least partly mediated by general auditory abilities.[82] Music aptitude is also associated with phonological awareness,[83–85] although this association can disappear when IQ is held constant[86] because of overlap between preexisting abilities. The situation is further complicated by the fact that aptitude and music training are associated with auditory short-term and working memory,[26–28,67,79,87–90] and aptitude and music training are markers of IQ in the general population.[4] Even when IQ is held constant,[84] however, aptitude is associated with language abilities (i.e., grammar) at 6 years of age.

Despite the overwhelming evidence that points to a contribution of genetics to aptitude and its correlates, there is an equally overwhelming bias in neuroscientific research to interpret correlational results as indicating that music lessons make one a better listener and perceiver of speech. Consider the titles and results of two articles published in 2013. One article ("Older adults benefit from music training early in life: biological evidence for long-term training-driven plasticity") compared older adults with no training to same-age adults who had some training but stopped taking music lessons more than 40 years earlier.[91] The music group had larger brain-stem responses to the syllable /da/ presented in the midst of noise. An article from a different research team ("Informal musical activities are linked to auditory discrimination and attention in 2–3-year-old children: an event-related potential study") had a neutral title but concluded that the "results highlight the significance of informal musical experiences in enhancing the development of highly important auditory abilities in early childhood" (p. 654).[92] Informal musical activities in the homes of 2- to 3-year-old children (either musical play by the child or singing by parents) predicted precocious neural responses when a repeating tone deviated in terms of frequency, duration, intensity, or the presence of a gap. Both findings are consistent with the view that genetically determined individual differences in auditory processing are consistent across the life span and predictive of involvement with music. In both instances, the authors mentioned near the end of their discussion sections that preexisting differences could be involved but quickly dismissed the idea with no mention that aptitude, auditory abilities, music listening, and musical achievement have a substantial genetic component.

Why is there a bias to infer from correlational data that music training causes improvements in speech perception and auditory skills? Although the field of behavioral genetics documented a genetic component to virtually all human behaviors, neuroscientists became fascinated with the notion of plasticity—the potential for our experiences to change our brain and behavior.[93] Sophisticated neuroimaging and electrophysiology techniques allowed researchers to document individual differences in brain structure and function as well as changes within individuals. One of the most exciting findings was that relatively short-term experiences, including musical experiences, lead to changes in brain and behavior.[10] After all, if short-term music listening or performing leads to such changes, then long-term exposure undoubtedly leads to even greater changes,[2] although this does not rule out a concomitant role for nature.

Researchers who interpret correlational data as showing that music training causes improvements in speech perception claim that their view is bolstered by two key findings. One is that duration (or quantity or intensity) of training is correlated with speech perception or other nonmusical abilities,[6,21,38,40,94] a finding that is actually consistent with nature or nurture perspectives. Children with little aptitude for music would be particularly unlikely to take music lessons for years on end, and duration of training is predicted by personality and general cognitive ability,[16] both of which are genetically influenced. One curious result is that the age when music training begins does not matter,[38,40,50] a finding inconsistent with the fundamental principle that plasticity is greater earlier in life, which suggests that plasticity is not the driving force in associations between music training and speech perception.

The second key finding comes from longitudinal designs, where researchers use pretest/posttest approaches to compare individuals who choose to take music lessons with other individuals.[31,92,95,96] Although greater improvements from pre- to posttest provide better evidence than comparisons conducted at a single point in time, genetically determined phenotypes can be evident later but not earlier in development (e.g., secondary sexual characteristics, schizophrenia, Huntington disease). In perhaps the best longitudinal correlational study of speech perception, 2 years of music classes in high school were associated with faster neural responding to a synthesized speech sound (/da/) presented in the midst of background noise.[96] A result as specific as this one, however, with no behavioral counterpart, does not prove that music lessons improve speech perception or address the role of preexisting differences.

In sum, interpreting correlational data as convincing evidence that music lessons cause improvements in speech perception is based on untenable premises, namely that (1) everyone is born an equally good listener; (2) the potential to become a skilled musician is the same for everyone; (3) preexisting individual differences in music aptitude are independent of music training; and (4) it is a coincidence that music training and music aptitude have similar associations with speech perception and auditory processing. Such a view is a form of radical environmentalism, which is as problematic as biological determinism.[97] A more sensible view is that children with good listening abilities are more likely than other children to take music lessons, which further enhances their listening skills—a classic example of a gene–environment interaction.[98]

Findings from studies of phonological awareness nicely highlight this point of view. Experimental studies reveal that music training can cause improvements in phonological awareness,[99,100] but, as noted above, phonological awareness is also associated with aptitude,[81–83] with IQ representing an additional complicating factor.[84] One informative approach for future research would be to examine whether effects of training differ for children as a function of preexisting differences in aptitude and IQ. My prediction is that such effects will be greater for children with higher aptitude and/or higher IQ because music training has a better fit with their genetic makeup. It is also possible, however, that children with lower aptitude and/or lower IQ would benefit more because they have more to gain. In general, detailed examination of gene–environment interactions will provide a more complete and accurate account of associations between music training and nonmusical abilities.

Conflicts of interest

The author declares no conflicts of interest.

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