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Music Training and Nonmusical Abilities

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Abstract

Music training is generally assumed to improve perceptual and cognitive abilities. Although correlational data highlight positive associations, experimental results are inconclusive, raising questions about causality. Does music training have far-transfer effects, or do preexisting factors determine who takes music lessons? All behavior reflects genetic and environmental influences, but differences in emphasis—nature versus nurture—have been a source of tension throughout the history of psychology. After reviewing the recent literature, we conclude that the evidence that music training causes nonmusical benefits is weak or nonexistent, and that researchers routinely overemphasize contributions from experience while neglecting those from nature. The literature is also largely exploratory rather than theory driven. It fails to explain mechanistically how music-training effects could occur and ignores evidence that far transfer is rare. Instead of focusing on elusive perceptual or cognitive benefits, we argue that it is more fruitful to examine the social-emotional effects of engaging with music, particularly in groups, and that music-based interventions may be effective mainly for clinical or atypical populations.

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INTRODUCTION

Does music training have beneficial side effects? For years, this question sparked the interest of researchers, policy makers, and the public. Its impetus came from a one-page article published in *Nature* (Rauscher et al. 1993), reporting that undergraduates' spatial abilities improved more after listening to a Mozart piano sonata than after hearing relaxation instructions or sitting in silence. Thus sprang the idea that music makes you smarter. With no supporting data, this notion spread from music listening to training and to very young, even unborn, babies, with ramifications for public policies. For example, by 1998, the state of Georgia proposed a budget to provide recordings of classical music to families of newborns.

Music training: formal group or individual lessons with a teacher, focused on learning how to sing and/or play a musical instrument

Far transfer: generalization of knowledge and skills from a trained domain to a substantially different domain (e.g., from music to mathematics)

The so-called Mozart effect took on a life of its own, with research activity peaking at the turn of the current century, only to die out ∼10 years later (Schellenberg 2012). As it turns out, the effect has nothing to do with Mozart (Schellenberg et al. 2007, Schellenberg & Hallam 2005) or with music specifically (Nantais & Schellenberg 1999). Stimuli that affect emotions can also influence cognition (Lerner et al. 2015, Pham 2007, Phelps et al. 2014, Thompson et al. 2001). Emotional responses to music are usually positive but short-lived, with a faster tempo eliciting higher arousal and major mode promoting positive mood (Husain et al. 2002). The arousal and mood hypothesis explains the Mozart effect as one example of a stimulus that improves performance because it increases arousal and positive mood (Thompson et al. 2001).

The possibility that music training enhances nonmusical abilities is a different story but more sensible intuitively. Music students are not just listening, but also learning to sing or play an instrument, a complex task that often involves years of practice. Nevertheless, as Thorndike & Woodworth (1901) noted more than a century ago, transfer of learning—when training in one domain affects performance in another domain—depends on cross-domain similarity. Near transfer can occur between highly similar domains, but far transfer—when the trained and the new domain differ substantially—occurs rarely. Recent meta-analyses show null effects of far transfer across different types of training, including chess, working memory, executive functions, video games, exergames, physical exercise, and music (Ciria et al. 2023; Gobet & Sala 2023; Kassai et al. 2019; Sala & Gobet 2017a,b). Working-memory (WM) training, for example, fails to provide sustained transfer from verbal to visuospatial WM (Sala & Gobet 2020b), let alone other abilities (Melby-Lervåg & Hulme 2013, Shipstead et al. 2012, von Bastian & Oberauer 2014). If efforts designed by experts fail to induce transfer, it seems unlikely that music lessons would spontaneously lead to benefits unrelated to music, such as enhanced language skills, visuospatial reasoning, or general cognitive ability. Moreover, in the absence of a solid theoretical rationale, the burden of proof lies clearly with those who posit that such benefits exist.

Proposals that music training has nonmusical side effects are relevant to debates on plasticity and domain specificity. Plasticity describes experience-dependent changes in behavior or brain structure and function. Because it decreases with age, plasticity is most likely if music lessons start early in childhood, although changes in the brain and behavior occur throughout the life span (Oberman & Pascual-Leone 2013, Sampaio-Baptista et al. 2018). Evidence for plasticity is provided when longitudinal experimental designs show that a change over time is present for individuals who had a specific experience, but absent for those who did not.

Domain specificity refers to independent neurocognitive systems (i.e., modules; Fodor 1983). According to Peretz and Coltheart (Peretz 2011, Peretz & Coltheart 2003), music processing involves modules specialized for music and other modules shared with language. Abilities would presumably not transfer across modules. Evidence for the independence of music and language comes from a double dissociation. Individuals with aphasia have impaired language production or perception but often intact musical ability (Racette et al. 2006, Warren et al. 2003), whereas individuals with amusia have impaired musical ability (Hyde & Peretz 2004) but often intact speech, hearing, and general cognitive ability (Ayotte et al. 2002, Dalla Bella et al. 2009, Peretz & Hyde 2003). Opposing views highlight shared mechanisms between music and language (e.g., Besson et al. 2011, Patel 2014).

Existing accounts of transfer from music training to nonmusical abilities are underdeveloped and fragmentary and rely primarily on correlational data, attempting to explain associations post hoc and hypothesizing that they are caused by music training. For transfer to speech perception, Patel's (2011) OPERA (overlap, precision, emotion, repetition, attention) hypothesis describes data collected mostly from a single laboratory (summarized in Kraus & Chandrasekaran 2010), which indicate that musicians have enhanced neural encoding of speech, as evidenced by stronger and more stimulus-faithful frequency-following responses to isolated syllables (e.g., /da/). The title of Patel's article—"Why Would Musical Training Benefit the Neural Encoding of Speech?"—presupposes a causal effect of music training, even though the author provides no evidence in this regard. Patel (2011, 2012) claims that this interpretation is defensible because duration of training correlates with the magnitude of neural enhancements, but duration of training is confounded with demographic, cognitive, and personality variables (Corrigall et al. 2013) and predicted by preexisting musical ability (Kragness et al. 2021). Some or all of these individual differences other than music training could explain neural responses to speech (Schellenberg 2015, 2019).

The original version of OPERA (Patel 2011) proposed that compared with speaking and listening in general, performing music requires more precise encoding of auditory signals. Because speech and music overlap in relying on audition, the additional sensory precision required for music is said to lead to more faithful neural responding to speech. Additional factors that promote cross-domain transfer are positive emotional responding to music and the repetition and focused attention that practicing music entails. In an update to his theory, Patel (2014) expanded the notion of precision to include cognitive processes shared by speech and language, specifically auditory working memory. Compared with speech, music training is claimed to place higher demands on auditory working memory, which in turn enhances neural responding to auditory

Working memory (WM): the ability to hold information temporarily in mind, manipulate it, and use it for cognitive tasks such as decision making

Plasticity: changes in behavior (behavioral plasticity) or brain structure and/or function (brain plasticity) caused by environmental factors

Musician: typically someone with more than a predetermined number of years of music training, the most common being six years stimuli. Degé (2021), by contrast, speculates that music training is a qualitatively special experience that improves executive functions, which could explain associations between music training and general cognitive ability. Although Patel (2011) and Degé (2021) present starting points for what could become models of why music training has far-transfer effects, their proposals are difficult to falsify. Another complicating factor is that in the literature more generally, the notion of music training is broad and undefined, typically considering many different types of training simultaneously, which makes it impossible to be precise about mechanisms of transfer.

Intelligence quotient (IQ): calculated from scores on standardized tests of intelligence or reasoning

The current review focuses on associations between music training and nonmusical abilities. For scholars who emphasize nurture (e.g., Tierney & Kraus 2013), music training is a good model of plasticity (e.g., Herholz & Zatorre 2012, Moreno & Bidelman 2014, Schlaug 2015), with perceptual and cognitive side effects extending beyond music. For those who emphasize nature, presumed transfer effects reflect preexisting differences in cognitive ability, musical ability, and personality, which determine who takes music lessons and for how long (Corrigall et al. 2013). In either case, musical activities play important social and emotional roles (Koelsch 2014, Swaminathan & Schellenberg 2015), which require no training or far transfer to emerge. A second focus concerns genetic and environmental contributions to musicality. Although high levels of musical expertise could be the sole consequence of training and practice, musical predispositions (acting in concert with demographic, cognitive, and personality variables) could also influence who takes music lessons and/or becomes a musician. In short, we aim to describe and explain the nonmusical correlates of music training and how predispositions contribute to musical expertise.

Music Training

Two assumptions are required if we are to believe that music training causes observed associations with nonmusical abilities (Schellenberg 2020). One assumption is that individuals who study music are similar to others before training, such that subsequent nonmusical differences depend on training. Another is that among musically trained individuals, the duration of their music training is independent of preexisting differences. Put differently, individuals who take lessons for years are similar at the outset to those who stop after a few months.

Both assumptions are problematic. Although music lessons and duration of training are typically considered to be causal variables, they may be more usefully considered as outcome variables. For example, among Canadian undergraduates, duration of playing music is predicted by demographics, personality, and cognitive ability, specifically parental education, openness-to-experience (hereafter openness), and intelligence quotient (IQ), respectively (Corrigall et al. 2013). For 10- to 12-year-old children, duration of music training also correlates with cognitive ability (IQ, average school grades), personality (openness, conscientiousness), and demographics (parental education, family income, age, duration of nonmusical out-of-school activities; Corrigall et al. 2013). For 7- and 8-year-olds, parental openness is the most reliable predictor of music training (Corrigall & Schellenberg 2015).

One possibility is that children from well-off families, with good cognitive abilities and certain personality traits, are more likely to take and persist in music lessons. Another possibility is that music training increases cognitive ability, grades in school, family incomes, parents' education, openness, and conscientiousness. A third possibility is that unidentified variables drive the associations. The first possibility is arguably the most parsimonious. Indeed, IQ differences between musically trained and untrained children can be as large as 1 SD (Schellenberg & Mankarious 2012), far larger than the effect sizes of modestly successful environmental manipulations (Protzko 2015), which suggests a role for predispositions. In any case, musically trained and untrained individuals certainly differ in multiple ways in addition to music training. Attributing correlational effects to experience is therefore unwarranted (Schellenberg 2019, 2020). In addition, claims that correlations with duration of training provide stronger causal evidence than do group comparisons are unjustified.

What about professional musicians, who have more musical experience than nonprofessionals with music training? Professionals score higher than nonprofessionals on musical ability and extraversion, and they are similar in openness and agreeableness (Vincenzi et al. 2022). Although nonprofessionals have higher cognitive ability than untrained individuals, professionals do not, meaning that the link between music training and cognitive ability is restricted to nonprofessionals. In contrast to predictions from transfer accounts, the association with cognitive ability is absent when musical experience is highest.

Deliberate practice: practice aimed at enhancing musical performance that involves highly structured activities and specific goals

Natural Musical Ability

In the second half of the twentieth century, the idea of natural musical ability—or musical aptitude—fell out of favor as domain-specific expertise was thought to result from practice, or deliberate practice in the case of musical achievement (Ericsson et al. 1993). Musical talent—the overt manifestation of natural ability—was similarly eschewed, despite examples that could not be attributed easily to the environment (e.g., Michael Jackson versus his siblings). Indeed, Howe et al. (1998, p. 399) concluded that innate talent is a myth, crediting achievements in music and other domains to "early experiences, preferences, opportunities, habits, training, and practice." Although this position now seems like radical environmentalism (Hambrick et al. 2018), it was consistent with the antinativist historical context.

Findings from behavioral and molecular genetics (Ullén et al. 2016) ensured that the view of musical achievement as an equal-opportunity employer—obtained by anyone who practices hard enough—fell by the wayside. Twin studies confirmed a genetic contribution to musical ability (Drayna et al. 2001, Mosing et al. 2014a), music practice (Butkovic et al. 2015, Hambrick & Tucker-Drob 2015), musical achievements (Hambrick & Tucker-Drob 2015), choice of genre and instrument (Mosing & Ullén 2018), associations between early onset of training and musical achievement (Wesseldijk et al. 2021b), and associations between music training and verbal (Gustavson et al. 2021, Wesseldijk et al. 2021a) or cognitive (Mosing et al. 2016) ability. Additional evidence for a genetic component to musical ability was provided by family (Peretz et al. 2007), biomolecular (Peretz 2008, Tan et al. 2017), and genome-wide (Gustavson et al. 2023) analyses. Whereas one genetic factor appears to account for associations between musical and general cognitive ability, a second factor accounts for associations among different aspects of musical ability (Mosing et al. 2014b).

Evidence of genetic contributions to musical ability coincided with the development of new measurement tools. The new tests were modeled after older musical-aptitude tests (e.g., Gordon 1965, Seashore 1919), which aimed to identify children who could benefit from music training—those with good natural ability. The term aptitude remained out of favor due to its emphasis on nature, such that the new tests are described as measuring musical competence [Musical Ear Test (MET); Wallentin et al. 2010], music-perception skills [Profile of Music Perception Skills (PROMS); Law & Zentner 2012], musicality (Swedish Musical Discrimination Test; Ullén et al. 2014), or musical abilities [Montreal Battery of Evaluation of Musical Abilities (MBEMA); Peretz et al. 2013]. These tests all require listeners to determine whether standard and comparison auditory sequences are identical, and even untrained listeners can take them. When the comparison differs from the standard, at least one tone is altered in pitch (melody subtests) or one interonset interval is changed in time (rhythm subtests). A shortened version of the PROMS (Mini-PROMS; Zentner & Strauss 2017) omits a rhythm subtest. Rather, in addition to a melody subtest, this test has tuning, tempo, and accent subtests, respectively, that require listeners to detect a mistuned tone in a three-tone major chord, a change in tempo for an entire melody, or a change in amplitude applied to one or more events in a sequence of drumbeats.

Informal musical activities: musical behaviors other than formal music lessons, including learning how to play an instrument by oneself

Although these tests do not measure all aspects of musical ability, they measure fundamental facets with good reliability and validity, and even the public acknowledges that these sorts of skills reflect variation in human musicality (Buren et al. 2021b,c). Thus, musical ability hereafter refers to performance on these tests. When analyzed in conjunction with music training, test performance allows us to identify incongruities, specifically musical sleepers—individuals with good ability but no training—and sleeping musicians—trained individuals with little natural ability (Law & Zentner 2012).

The notion of natural musical potential would mean little, however, if it does not represent a stable trait. In a longitudinal study of musical ability, Kragness et al. (2021) tested children at age 8 with the MBEMA and again at age 13 with the MBEMA and the MET. A principal component was extracted at both time points to reduce measurement error and because the shared variance was most likely to represent true musical ability. The correlation from time 1 to time 2 ($r \cong 0.7$) was similar to that observed for IQ, presumably the most stable human trait (Plomin et al. 1994). Although musical ability correlated with duration of music training at both time points, music training did not predict ability at age 13 after accounting for earlier ability, but ability at age 8 predicted ability 5 years later after accounting for training. Ability at age 8 also predicted how much music training children had in the subsequent 5 years. In short, musical ability was stable over time and unaffected by music training.

Even though musical-ability tests are designed to measure natural ability, associations with music training are used as evidence for their validity (Law & Zentner 2012, Peretz et al. 2013, Wallentin et al. 2010, Ullén et al. 2014). Such associations are identified frequently (Bhatara et al. 2015; Correia et al. 2022b; Kragness et al. 2021; Palomar-García et al. 2020; Schellenberg et al. 2023; Slater & Kraus 2016; Swaminathan & Schellenberg 2017, 2018, 2020; Swaminathan et al. 2017, 2018; Vanden Bosch der Nederlanden et al. 2020; Witek et al. 2023). Duration of music training (a continuous variable) also correlates with higher scores, whether testing is conducted in person (Swaminathan et al. 2021, Vanden Bosch der Nederlanden et al. 2020) or online (Correia et al. 2022b). For individuals with no music training, performance correlates with informal musical activities (Correia et al. 2023).

Determining the causal direction between musical ability and music training is like the chicken-and-egg problem. Individuals with low ability would be unlikely to take music lessons for years, ensuring a positive correlation between ability and training. If music training has transfer effects, however, near transfer (i.e., to tests of musical ability) is the most likely possibility, and such effects should be greater for children who start music training early in life (e.g., by age 7; Penhune 2020). In our laboratory, we find a correlation between duration of music training and musical ability as measured by the MET, but this association is independent of the age at which training begins (Correia et al. 2022b, Swaminathan et al. 2021). These results are more consistent with ability determining training than training determining ability.

In one longitudinal study (James et al. 2020a), 10- to 12-year-olds who joined a school orchestra were compared with a group exposed to music via listening, theory, and practice. Group assignment was random but by class rather than by individuals. After one year, the orchestra group had higher musical ability than did controls, but this difference did not increase during the second year. Perhaps a small amount of training improved children's ability to cope with the task demands (Gordon 1989), which required identifying whether standard and comparison sequences differed in terms of pitch, time, or neither (i.e., three response options rather than two). In other words, the test relied on executive and musical abilities. Classroom assignment also meant that group dynamics could have influenced performance.

Although the melody and rhythm subtests from the MET are equally difficult, music training correlates more strongly with the melody subtest (Correia et al. 2022b, Swaminathan et al. 2021). This result could reflect plasticity and near transfer due to Western music's emphasis on pitch, such that different results would emerge if participants came from a culture where the emphasis is on rhythm (e.g., some genres of African music). Melody discrimination also correlates with proficiency in a tonal language (Liu et al. 2023, Swaminathan et al. 2021), and musical ability is unlikely to affect who learns a tonal language. Rather, learning to attend to changes in pitch appears to enhance performance on melody-discrimination tasks. The rhythm subtest, by contrast, is less susceptible to experience but more strongly associated with stable individual differences such as general cognitive ability (Correia et al. 2022b). Rhythm-discrimination abilities are also associated with the range of tempi that determine accurate and consistent tapping (Ladányi et al. 2023), which suggests that they are markers of basic temporal processing.

Socioeconomic status (SES): position of an individual (or their family) in society as determined by factors such as income and education

In our work, we attempt to disentangle influences from nature and nurture by measuring musical ability and music training. With music training held constant, associations with musical ability should reflect predispositions, possibly combined with informal engagement with music. Conversely, accounting for musical ability—particularly in musically untrained individuals—allows for a clearer interpretation of effects putatively caused by training: Are they specific to trained individuals, as expected if music training plays a unique causal role; or are they observed in untrained individuals with good musical ability (i.e., musical sleepers)? The different musical-ability subtests also allow us to test proposals that rhythm abilities are particularly important for language processing.

Outline

Because of the sheer volume of available evidence, our review draws heavily on recent reviews and meta-analyses. We also consider empirical reports published since 2015, most of which appeared after those examined in earlier reviews (Schellenberg & Weiss 2013, Swaminathan & Schellenberg 2016). We discuss studies of music training and its association with listening abilities, language, general cognitive abilities, and social-emotional functioning. Each section begins with a discussion of meta-analytic evidence and review articles, followed by a survey of correlational evidence, and ends with an overview of longitudinal studies.

LISTENING ABILITIES

Musically trained individuals often outperform their untrained counterparts on tasks that require them to analyze complex auditory scenes (Bregman 1990) or to discriminate auditory stimuli that vary in pitch and time. Alain et al. (2014) suggested that music lessons cause such advantages, which could in turn ameliorate age-related decrements in auditory perception. Recent meta-analyses also indicate that music training improves listening skills, at behavioral and brain levels, but the effect is small, publication bias cannot be ruled out, and methodological limitations preclude firm conclusions (Neves et al. 2022, Román-Caballero & Lupiáñez 2022).

In any event, correlational and cross-sectional studies confirm that even when musically trained and untrained participants are matched in age, sex, socioeconomic status (SES), and nonverbal IQ, trained individuals can more successfully discriminate complex tones that differ in frequency, detect temporal changes in presentation rate, and track a voice in the presence of another voice (Madsen et al. 2019). Music training also predicts enhanced fine-grained frequency and temporal processing among older adults with or without hearing loss (Bianchi et al. 2019).

Moreover, frequency-discrimination skills are superior among amateur choir singers compared with nonsingers (Tremblay & Perron 2023), and, compared with nonmusicians, trained musicians identify shorter silent gaps in the midst of white noise (Donai & Jennings 2016). Musicians also show less interference when asked to identify a 20-ms pure tone followed by 300 ms of noise (Yoo & Bidelman 2019) or to attend selectively to pitch and duration cues in speech (Symons & Tierney 2023). Even after controlling for musical ability, IQ, and short-term memory (STM), musicians are better at detecting changes in 1-s auditory scenes comprising four events (e.g., animal or environmental sounds; Vanden Bosch der Nederlanden et al. 2020). In an electroencephalography (EEG) study, musicians outperformed nonmusicians in a pitch-discrimination task and showed marginally stronger correlations between pitch changes and the amplitude of brain responses, even though group differences disappeared after correction for multiple comparisons (Kim et al. 2023).

Electroencephalography (EEG): an electrophysiological technique that records electrical brain activity using electrodes attached to the scalp

Correction for multiple comparisons: statistical adjustments to avoid type I errors (finding an effect that does not really exist), which are more likely when multiple tests/comparisons are conducted

Active control group: participants who are assigned to nonmusical but similarly stimulating activities, intended to control for expectations or nonmusical components of music training (e.g., contact with an adult instructor)

Mismatch responses: EEG responses to deviant (rare) stimuli presented among standard (frequent) ones, which differ on dimensions relevant to the research question (e.g., pitch)

Perhaps the most convincing causal evidence that music training improves listening skills comes from a 10-week choir-singing program for older adults, which documented greater improvement in pure-tone frequency discrimination for the choir group than for a passive control group (Dubinsky et al. 2019). Nevertheless, the choir group comprised seniors who enrolled in a singing course (i.e., self-selected), and there was no active control group. Thus, the music group may have been more motivated to do well on the listening tests, particularly if choir participation was a positive social experience (Johnson et al. 2020, Pentikäinen et al. 2021). In another longitudinal study, adolescents assigned to music-listening training—but not those in a passive control group—had better hearing thresholds after two weeks and improved discrimination of tones that differed in intensity, frequency, and onset ramp (Schneider et al. 2022). The two-way (time × group) interaction was significant for only one test (intensity: $p = 0.045$), however, and there was no correction for multiple comparisons.

When behavioral tasks are combined with EEG, children who take a piano-training intervention for six months show neural improvements (i.e., enhanced positive mismatch responses) for processing pitch changes, which differ from those of reading-training and passive controls (Nan et al. 2018). The neural advantage is not reflected in behavior (pitch discrimination), though, for which the three groups improve similarly. The relevance of brain advantages for listening skills is also unclear because most brain–behavior correlations are not significant.

In brief, correlational evidence documents positive associations between music training and listening skills without informing the issue of causation. Good listeners could gravitate toward music training and/or music training could improve listening skills. Although summaries of the literature suggest that music training plays a small causal role, recent data raise doubts about reliability, while methodological and statistical concerns further preclude unequivocal interpretations.

LANGUAGE ABILITIES

Evolutionary accounts of musicality often rely on comparisons with language (Brown 2017). Such accounts are consistent with hypotheses that experience in music could affect language skills (Pino et al. 2023). A recent meta-analysis reported positive effects of music training on behavioral tasks that index linguistic processing and on brain measures of speech and prosody perception (Neves et al. 2022). Other reviews concluded that successful musical interventions are most likely to focus on active instrumental learning (Román-Caballero et al. 2022) or to combine movement with music training (Sinn et al. 2022). These conclusions remain equivocal, however, because effect sizes are small and limited by suboptimal study designs and methods. In neuroscientific studies, for example, inferences based on one syllable (/da/) produced by a single speaker or synthesized (e.g., Dubinsky et al. 2019, Hennessy et al. 2021, Tierney et al. 2015) may have limited functional relevance or generalizability.

Much research focuses on speech perception, the auditory component of language. As noted, the OPERA hypothesis (Patel 2011, 2012, 2014) proposes that learning to play music requires extra precision in auditory processing compared with everyday listening to speech and that these additional demands enhance the neural encoding of sound (Strait & Kraus 2014) and improve speech perception. Another view holds that rhythm production and training (e.g., drumming) has a special association with speech perception, based on temporal-processing deficits in dyslexia that explain difficulty in isolating speech sounds (Goswami 2018, Tallal 2004, Wolff 2002). In general, children with developmental language disorders tend to have poor rhythm abilities (Cumming et al. 2015). Fiveash et al. (2021) propose that training in rhythm could enhance speech and language processing, and ameliorate developmental language problems, because both rhythm and speech require sensorimotor coupling, precise auditory processing, and synchronization to external signals.

Magnetic resonance imaging (MRI): a neuroimaging technique that produces images of brain structure (i.e., MRI) or function (i.e., fMRI)

Speech in Noise

Research on speech-in-noise (SIN) perception examines listeners' ability to understand speech presented simultaneously with white noise, another talker, or multi-talker babble. A review by Coffey et al. (2017) confirms that many studies report musician advantages on SIN tasks, such as when speech is presented with a masker sentence (Başkent & Gaudrain 2016) or when spoken syllables are presented with a white-noise masker (Du & Zatorre 2017). The musician advantage tends to be larger for more difficult tasks, such as when masker sentences are intelligible or colocated with targets (Swaminathan et al. 2015). SIN perception tends to decline with age, but less so for musicians (particularly women) than for nonmusicians (Merten et al. 2021). When listeners are asked whether a standard melody is the same as a comparison melody presented in musical noise (Coffey et al. 2019), performance is correlated with SIN perception, and musicians outperform nonmusicians. Evidence for a special role for rhythm abilities comes from findings showing that rhythm but not melody scores from the MET predict performance on SIN tasks and that percussionists outperform nonmusicians, with vocalists falling in between (Slater & Kraus 2016).

Correlational studies report positive associations between music training and SIN performance in some instances (e.g., Başkent & Gaudrain 2016, Du & Zatorre 2017, Merten et al. 2021, Swaminathan et al. 2015, Zendel et al. 2015), but replication failures are also frequent (e.g., Başkent et al. 2018; Boebinger et al. 2015; Madsen et al. 2019; Mussoi 2021; Perron et al. 2021, 2022; Yeend et al. 2017; Zendel & Alexander 2020). One particularly confusing result comes from a cross-sectional study of choir singers and nonsingers who varied widely in age: SIN performance did not differ between groups, but singers' scores correlated with duration of training, practice, and being able to sing in more than one language (Perron et al. 2022). Madsen et al. (2017) also found no difference between musicians and nonmusicians at perceiving SIN, even though musicians had better frequency discrimination, whereas Yoo & Bidelman (2019) reported a smaller association between musicianship and SIN perception when WM was held constant. The suggestion from Zhang et al. (2021) that music training prevents or limits age-related decrements in SIN perception ignores the possibility that predispositions are involved. Moreover, differences in methods across tasks and studies preclude a clear understanding of when associations with music training are most likely to emerge (Coffey et al. 2017).

In one magnetic resonance imaging (MRI) study, structural differences in the arcuate fasciculus of musicians correlated with SIN performance, and this association was mediated by superior temporal activity during a SIN task (Li et al. 2021). Because the arcuate fasciculus is part of the sensorimotor system, the advantage for musicians in SIN perception could reflect more efficient sensorimotor coupling. This idea is consistent with previous functional findings of more specific phoneme representations and stronger functional connectivity across auditory and motor regions

El Sistema: founded in Venezuela in 1975, a program that offers ensemble music lessons (typically daily, after school) to underprivileged children as a means of rectifying social inequality

Attrition: proportion of participants who leave a study before it finishes

Event-related potentials (ERPs): EEG responses to specific events or stimuli, with distinct ERP components (e.g., N1, P2) thought to reflect distinct perceptual/cognitive processes

Random assignment: determining group membership in an experiment at random, such that any participant is equally likely to be assigned to the experimental or control group

in musicians compared with nonmusicians (Du & Zatorre 2017). Older musicians also decode noise-masked audiovisual syllables better than their nonmusician counterparts do, and they have preserved phoneme representations in visual and sensorimotor regions that are comparable with those of younger nonmusicians (Zhang et al. 2023). Compared to older nonmusicians, older musicians additionally have activation patterns in sensorimotor regions that are more similar to those of younger nonmusicians, even though the magnitude of similarity does not correlate with behavioral performance.

Does music training improve SIN perception? In one study, 8-year-olds were assigned randomly to community-based (El Sistema–inspired) music training for two sessions per week (Slater et al. 2015). A wait-list control group started a year later. After two years, children with two years of lessons had better SIN performance than did those with one year of lessons. Nevertheless, attrition was more than 50%, and the analysis included only 19 children per group. It is also unclear why an extra year of music training was crucial at one point in time, when the control group also had training, but not earlier when the control group had no training.

When Zendel et al. (2019) randomly assigned older adults to six months of music, video game, or no training, the music group showed SIN improvement from pre- to posttest only when the background noise was particularly loud, yet the three-way (group × time × noise) interaction was not significant. Event-related potentials (ERPs) from the same study revealed that music training predicted increased amplitude (not latency) of the N1 component (thought to reflect the encoding of basic acoustic features of speech) during passive listening. Music training also predicted positive-going brain activity (200–1,000 ms, thought to reflect strengthened auditory-motor coupling) during active listening. For passive listening, however, this effect was restricted to the 700–1,000-ms time window and in the opposite direction (i.e., decreased amplitude for trained participants). Moreover, attrition was 24%, and the final sample had only 34 participants, with only 8 in the video game group, which could explain the convoluted ERP results.

In another sample of older adults who participated in a 10-week choir-singing program, enhanced SIN improvements were evident and mediated by improvements in frequency discrimination, but the study did not have random assignment (Dubinsky et al. 2019). Indeed, when Hennessy et al. (2021) randomly assigned 50- to 65-year-olds to a choir or control group for 12 weeks, improvements in SIN perception were similar across groups. Moreover, effects in brain responses were limited to the N1, which had decreased latency in the active SIN task but not in the passive task, and increased amplitude in the passive task but not in the active task.

In short, longitudinal studies provide little evidence of a causal link between music training and SIN, and attrition often poses a problem. Moreover, because nonmusicians with good musical ability (musical sleepers) show enhanced neural processing of noise-degraded speech (Mankel & Bidelman 2018), natural musical ability rather than training may account for associations with neural responses to speech.

Linguistic and Emotional Prosody

Speech prosody refers to variations in pitch, loudness, timing, and voice quality. Emotional prosody describes when these cues communicate the speaker's emotional state, whereas linguistic prosody describes linguistic and pragmatic functions such as word stress, sentence focus, and differences in pitch contours between statements and declarative questions. Recent reviews confirm that music training correlates positively with the ability to recognize emotions conveyed by prosody (Martins et al. 2021, Nussbaum & Schweinberger 2021).

In one instance, musicians were better at recognizing happy, sad, or neutral emotions in faces or humming voices presented simultaneously (Weijkamp & Sadakata 2017). On half of the trials, the emotion conflicted between the voice and the face. When asked to attend to the voice or the face, musicians identified the emotion better and were less influenced by the conflicting information. Nevertheless, there were only 16 participants per group and no measure of general cognitive ability. In another study, young adults were presented with audio, visual, or audiovisual clips and asked to identify the emotion expressed via prosody. Musicians outperformed nonmusicians in the auditory condition only (Farmer et al. 2020). In another study, adults listened to eight excerpts of music and nine extracts of speech and made continuous ratings of arousal and valence for each (Dibben et al. 2018). Music training was associated with arousal for only one music excerpt and with valence for a different excerpt. A clearer positive association was evident when 12-year-olds with 5 years of music lessons or no lessons were asked to discriminate phonetically identical sentences that varied only in prosody (Stepanov et al. 2018).

Pinheiro et al. (2015) presented young-adult musicians and nonmusicians with spoken utterances that differed in emotional prosody (happy, angry, neutral) and semantic content (intelligible or unintelligible). Although musicians outperformed nonmusicians at recognizing anger in unintelligible sentences (one of six conditions), the three-way (group $\times$ emotion $\times$ intelligibility) interaction fell short of significance ($p = 0.052$), and there was no correction for multiple comparisons. The EEG findings were similarly circumscribed: Musicians had reduced P50 amplitude for the intelligible stimuli; for P50 and N1, stimulus type did not affect EEG responses for musicians, but it did for nonmusicians, with greater negative amplitude for unintelligible stimuli. Null associations with music training have also been reported when second to fifth graders were tested for prosodic awareness (Flagge et al. 2021), 11- to 14-year-olds determined the emotion conveyed by nonsense words (Başkent et al. 2018), and young adults made forced-choice judgments about the emotion expressed by semantically neutral sentences (Park et al. 2015). The use of glides rather than discrete pitches in speech likely contributes to poor performance and inconsistent findings (Haiduk et al. 2020).

Psychoacoustic-like tasks can be used to examine specific dimensions of prosody. For example, musicians outperform nonmusicians at discriminating the pitch of the five lexical tones used in Thai, whether tones are presented in normal speech, low-pass filtered, or reproduced on a violin (Burnham et al. 2015). Musicians are also better at identifying specific talkers (Xie & Myers 2015), remembering vocal phrases (Haiduk et al. 2020), discriminating statements from declarative questions (Zioga et al. 2016), and detecting pitch or duration changes to eight-word phrases or their pure-tone analogs (Sares et al. 2018). Compared with former musicians, active musicians are better at detecting pitch changes in the final word of sentences, and both groups outperform nonmusicians (Toh et al. 2023).

In a study from our laboratory, 169 participants made forced-choice judgments about the emotions expressed by voices, either from prosody or nonverbal vocalizations (e.g., laughter) or from faces (Correia et al. 2022a). A small advantage for musically trained listeners on both auditory tasks was fully mediated by musical ability, yet the association between ability and emotion recognition remained evident when music training was held constant. Moreover, musical sleepers were equivalent to musicians at identifying vocal emotions, which suggests that musical ability can explain associations between music training and emotion recognition. Indeed, when musical ability is held constant, the positive association between music training and detection of changes in pitch (melodic contour) or pitch-accent timing in nonsense words can vanish (Morrill et al. 2015).

In one longitudinal study, nonmusician college students were assigned to four weekly sessions that focused on identifying happiness, sadness, fear, tenderness, or anger in music or visual art (Mualem & Lavidor 2015). Only the music group improved over time at recognizing emotions in spoken utterances, but highly trained musicians had no recognition advantage over musically untrained participants with voices or even with music, even though they had better melody and rhythm discrimination. In another eight-week intervention with two sessions per week, English speakers were asked to discriminate a Mandarin word (/yu/) presented with one of four lexical tones (Wiener & Bradley 2023). Music training did not improve performance more than Mandarin training did. In short, we could find no evidence for a causal effect of music training on prosody perception. In an older study, often considered to provide such evidence, more than 70% of children who began the study did not return for posttesting (Thompson et al. 2004).

In sum, musical ability is often found to correlate with prosody perception, but there is no evidence for causation. Perhaps effects of music training are more reliable for atypically developing individuals who have greater room for improvement. For example, Jiam & Limb (2020) suggested that music training improves emotion recognition and the perception of prosody for children with cochlear implants. They also included the caveat that firm conclusions require better-designed studies with comparable auditory but nonmusical control interventions.

Grammar/Syntax

Recent research on grammar or syntax focuses on musical ability rather than training. Wiens & Gordon (2018) propose that improving the ability to perceive and remember rhythmic structures enhances temporal processing and sensitivity to prosodic markers of speech units, such that syntactic abilities improve. We found no reviews or meta-analyses on musical expertise and grammar, probably because not enough studies have been done.

In one instance, a positive association between rhythm perception and expressive use of grammar ($r \cong 0.7$) was evident for 6-year-olds after controlling for nonverbal IQ, duration of music training, or SES (Gordon et al. 2015c). This association with rhythm was subsequently extended to more complex syntactic forms (Gordon et al. 2015b). Among 5- to 7-year-olds, the association between grammar and rhythm ability is not mediated by auditory WM, IQ, or prosody perception (Nitin et al. 2023). For children with a wider age range (7- to 17-year-olds), rhythm-discrimination skills correlate with grammar even after controlling for age, gender, music training, SES, and WM (Lee et al. 2020). Nevertheless, evidence for a special association between grammar and rhythm requires weaker or null associations between grammar and other musical abilities, which were not measured.

In another sample of 5- to 7-year-olds, grammatical ability was examined in relation to the tempo of the children's spontaneous tapping and the range of tempi that constrained children's ability to tap accurately (Ladányi et al. 2023). A wider range predicted better receptive grammatical skills even after accounting for age, music training, SES, nonverbal IQ, and diagnosis of a language disorder. Additional evidence for a link with rhythm comes from 5- to 8-year-olds' grammaticality judgments about spoken sentences, which are better after simply hearing a strong-meter compared with a weak-meter rhythm (Chern et al. 2018). Because this rhythmic-priming manipulation does not affect mathematical or visuospatial skills, it does not appear to stem from mood or other extraneous factors. Similar priming effects are also evident for children with developmental language disorder (Bedoin et al. 2016) or cochlear implants (Bedoin et al. 2018).

In our laboratory, we pitted musical ability against music training, asking how these variables are associated with grammaticality judgments among 6- to 9-year-old children (Swaminathan & Schellenberg 2020). The musical-ability test (MBEMA; Peretz et al. 2013) had melody, rhythm, and memory-for-music subtests. The grammar test required matching spoken sentences to one of four pictures (Bishop 2003). Grammar scores correlated positively with music training and with musical ability, but the association with training disappeared after accounting for musical ability; in contrast, the association between grammar and musical ability was evident when IQ, age, openness, and music training were held constant. When subtests of musical ability were examined separately, an association was evident for rhythm but not for melody. An association with memory-for-music was also evident, however, and similar in magnitude to that observed for rhythm, which raises doubts about the proposed special link with rhythm. Moreover, in a similar study of preschoolers, grammatical ability correlated with melody discrimination but not with rhythm, pitch, or tempo discrimination, even after holding constant general cognitive ability (Politimou et al. 2019).

In sum, we found no evidence that music training improves grammatical abilities. Moreover, associations with music training are not particularly common, although correlations with musical ability are frequent. The hypothesized special association between rhythm ability and grammar may emerge only when no other aspects of musical ability are measured or when rhythm ability is compared specifically with melody ability.

Reading and Prereading Abilities

Young children learn about correspondences between speech sounds and written letters. Phonological awareness refers to the ability to isolate and segment speech sounds—either phonemes or syllables—which is crucial for letter–sound mapping and ultimately for reading. Based on evidence that rhythm abilities correlate with phonological awareness, Goswami (2018) proposed that rhythm training improves the fine-grained temporal processing necessary for discerning within-syllable units of language, such as the perception of voice-onset time, which determines the difference between words such as *pat* and *bat*, or *pat* and *pad*. Indeed, one meta-analysis concluded that music training in childhood induces a small but heterogeneous benefit in phonological awareness, but not necessarily in reading ability (Gordon et al. 2015a). A second meta-analysis of participants with reading difficulties came to a similar conclusion (Cancer & Antonietti 2022). A third concluded that music training has a small positive effect on literacy skills (Román-Caballero et al. 2022), but inclusion of studies that used other measures of linguistic processing (e.g., vocabulary) precluded specific conclusions about reading and prereading.

If music training has a positive causal effect on reading and prereading abilities, an association between music training and reading should be evident in real-world contexts. Nevertheless, the findings are inconsistent. For example, in one quasi-experimental study, phonological awareness of 5- to 7-year-olds who had one year of private music instruction was similar to that of their counterparts who had only school music classes (Eccles et al. 2021a). The literature is also rife with interpretive problems, such as those highlighted by a study that compared high school students who enrolled in a band program with those who joined premilitary training (Tierney et al. 2015). After three years, the band group improved more in phonological awareness and brain responses to auditory stimuli. The causal inference in the article's title ("Music Training Alters the Course of Adolescent Auditory Development") ignored the possibility that nonmusical individual differences were confounded with the choice of music over military training. Furthermore, high rates of attrition (41%) raise doubts about whether the 40 remaining participants were similar to the 28 who left. Finally, although there were three outcome measures (phonological awareness, phonological memory, naming), the crucial interaction between group and time ($p = 0.026$) was not corrected for multiple comparisons, and the two other tests had null results.

Indeed, suggestive evidence for a role of preexisting nonmusical differences emerged in a study of 4- to 7-year-olds, which found that children from families who self-selected into music training had better phonological awareness at the beginning of the study compared with passive controls, although this difference increased after six months of lessons (Skubic et al. 2021). More generally, meta-analytic evidence confirms that participants often have better cognitive and academic performance before they opt to take music lessons (Román-Caballero et al. 2022).

By contrast, associations between musical ability and reading skills tend to be positive and consistent in the literature. For example, when musical ability is measured as 9- to 12-year-olds' ability to learn a song, it correlates positively with phonological awareness (Degé et al. 2020). When musical ability is measured more traditionally among 4- to 5-year-olds, it predicts improvements

Mismatch negativity (MMN): early negative EEG response, typically studied in the auditory domain, to deviant (rare) stimuli presented among standard (frequent) ones

in phonological awareness over the next two years (Kempert et al. 2016). Evidence for a special role for rhythm comes from a study of 3- and 4-year-olds, whose rhythm-discrimination abilities were better than their melody-discrimination ability at predicting phonological awareness (Politimou et al. 2019). Steinbrink et al. (2019) asked whether phonological awareness correlates with music tests that are pitch based, involving tone or melody discrimination, or time based, involving tempo discrimination, rhythm discrimination, or rhythm reproduction. Rhythm reproduction was the strongest predictor of phonological awareness for 5-year-olds and for 8-year-olds. Moreover, among 9-year-olds, duration discrimination—another way of measuring temporal processing—predicts phonological awareness and its subsequent improvement (Sun et al. 2022).

Other findings raise doubts, however, that temporal skills—including those involving rhythm—are particularly important. For example, among English-speaking 5-year-olds, phonological awareness is not correlated with melody discrimination, rhythm discrimination, or rhythm reproduction, except when children are asked to tap the rhythm of a familiar song (Tsao et al. 2023). Among 6-year-olds, phonological awareness can correlate similarly with melody or rhythm discrimination (Degé et al. 2015, Janurik et al. 2022). In a study of Chinese-English bilingual third graders, both duration discrimination and pitch discrimination were associated with phonological awareness in both languages (Zhang et al. 2017). Melody discrimination is also associated positively with phonological awareness among 6-year-olds (Chung & Bidelman 2021), and for three different samples of children ranging from 5 to 8 years of age, phonological skills were more strongly associated with melody than with rhythm skills (Culp 2017, Eccles et al. 2021b, Lukács & Honbolygó 2019). Even for young adults, phonological awareness is better predicted by simple pitch discrimination than by rhythm discrimination (Sun et al. 2017).

In a study from our laboratory, we measured the reading ability of 166 undergraduates who were either native or non-native English speakers, as well as duration of music training, musical ability, general cognitive ability, and SES (Swaminathan et al. 2018). Reading ability for relatively complex texts was measured as a combination of comprehension and speed. Performance was better among native English speakers and participants with more music training, but there was no association with musical ability. The association with music training disappeared, however, when general cognitive ability was held constant. Thus, cognitive ability may determine duration of music training and reading ability, at least for higher-level reading skills. Perhaps associations between musical ability and reading are stronger earlier in development or on easier tests. In fact, when 8- to 11-year-old children were asked to match sentences with pictures or to segment letter strings into words, musical ability predicted reading even with music training and IQ held constant, but music training did not predict reading after accounting for musical ability and IQ (Partanen et al. 2022). Neural auditory processing [i.e., mismatch negativity (MMN)] in the same study did not correlate with reading skills.

Perhaps the clearest recent evidence for a causal effect of music training on phonological awareness comes from a study of 4- to 6-year-olds, who were assigned randomly to 14 weeks of training in music, phonological skills, or sports, with 3 20-min sessions per week (Patscheke et al. 2016). Increases in phonological awareness were similar for the music and phonological training groups and exceeded those of the sports group. In another instance, when 3- and 4-year-olds received music or visual arts classes over a year in prekindergarten, phonological awareness improved more in the music group (Vidal et al. 2020). Even attendance at music play school for two years appears to enhance phonological awareness and vocabulary for 5- to 6-year-olds (Linnavalli et al. 2018). In a study of actual reading ability, 8-year-olds were assigned randomly to eight months of twice-weekly training in music—primarily rhythm perception and production—or visual arts or to a passive control group (Rautenberg 2015). Improvement in reading accuracy was greatest for the music group, even after accounting for general cognitive ability and SES, and accuracy scores correlated with rhythm but not with melody perception.

Despite this positive evidence, when 160 kindergarteners were assigned randomly to 19 weeks of music training, motor-skills training, or a passive control group, improvements in phonological awareness were similar across groups (Bolduc et al. 2021). Moreover, when 74 kindergarteners were assigned randomly to 6 months of piano, reading, or no lessons, changes in word discrimination from pre- to posttest were indistinguishable between the piano and reading groups (Nan et al. 2018). Although by the end of the study the piano group outperformed the reading group at discriminating Mandarin words that differed by a single consonant, the two groups improved similarly at detecting vowel or tone changes. The reported advantage for consonants ($p = 0.046$) was lacking in theoretical motivation, uncorrected for multiple comparisons, and evident only when posttest scores were analyzed on their own.

Other findings indicate that adding music training to remedial programs does not accelerate improvement for 4- to 5-year-olds who have weak phonological awareness skills (Kempert et al. 2016) and that adding a one-year music program to a second-grade curriculum does not accelerate phonological awareness or reading compared with controls (Lukács & Honbolygó 2019). Findings that 18 months of music training improves the ability of 7- to 12-year-olds to read complex nonsense text (Barbaroux et al. 2019), or that one year improves 3- to 6-year-olds' phonological skills and vocabulary (Hutchins 2018), come from studies without control groups or random assignment.

Because children with dyslexia have difficulties with reading and rapid temporal processing (Lifshitz-Ben-Basat & Fostick 2019), improving their rhythm and temporal skills could improve their reading ability (Habib et al. 2016, Reifinger 2019). Even for adults with dyslexia, greater rhythm impairments predict greater difficulty with reading (Boll-Avetisyan et al. 2020). One review found positive effects of music training in 21 out of 23 studies of individuals with dyslexia, although the quality of the evidence was not evaluated (Rolka & Silverman 2015). In an exemplary, preregistered study, 8- to 11-year-olds with dyslexia were assigned randomly to music or painting classes for 1 hour twice weekly for 30 weeks (Flaugnacco et al. 2015). The music program focused specifically on rhythm. Improvements in phonological awareness and in reading words or nonwords were greater for the music group.

Another intervention study concluded that their findings "clearly encourage the use of active music training for the rehabilitation of children with language impairments" (Frey et al. 2019). This statement was based on larger MMN and N1 responses to voice-onset time differences in syllables after 6 months of music rather than painting training, even though behavioral improvements on 17 measures of phonological and cognitive processing were identical across groups. Unlike training in Flaugnacco et al.'s (2015) study, the music training provided by Frey et al. (2019) was not tailored to focus on rhythm or temporal skills. When rhythm training has been incorporated into interventions for children with dyslexia, it has some success at improving phonological awareness (Cancer et al. 2020), in line with Goswami's (2018) predictions. Nevertheless, music training emphasizing other aspects could be similarly effective.

In sum, evidence that music training improves phonological awareness for typically developing individuals is scarce and inconsistent. Although musical ability is often associated with phonological awareness, such associations may not extend to reading comprehension in adulthood, and a special role for rhythm ability remains an open question. For individuals with dyslexia, some results are promising, but successful interventions tend to focus specifically on improving temporal processing, such that they may differ from typical music training.

Second-Language Ability

Turker & Reiterer's (2021) review concluded that musical ability predicts second-language (L2) skills, as did an earlier review (Milovanov & Tervaniemi 2011). Studies published recently are mostly correlational and tend to focus on musical ability rather than training. For example, when Dutch adults are asked to discriminate Spanish words differing phonetically or in stress, performance correlates with musical ability (Vangehuchten et al. 2015). For Azerbaijani adults who receive 2–3 weeks of training in English pronunciation, improvement in L2 phoneme discrimination correlates with melody discrimination (Ghaffarvand Mokari & Werner 2018). Rhythm- and melody-discrimination abilities also distinguish Turkish children who are studying English from their monolingual counterparts (Roncaglia-Denissen et al. 2016). For 7- and 8-year-old Spanish children, duration and pitch discrimination predict phonological awareness in English (Pujazón 2021). Rhythm ability also predicts French-speaking young adults' ability to produce English words (Cason et al. 2020).

In our laboratory, we asked English-speaking undergraduates to discriminate speech sounds that are phonemic in a foreign language (Zulu) but not in English (Swaminathan & Schellenberg 2017). Performance was not associated with duration of music training, but it was associated with rhythm ability (but not melody ability), even when music training and general cognitive ability were held constant. For French adults, L2 proficiency, measured as lifetime duration of studying L2s, correlates with music training and with rhythm but not melody ability (Bhatara et al. 2015). When the same question is asked about Portuguese adults' proficiency in English (measured with self-reports of comprehension, reading, etc.), associations with rhythm ability, melody ability, and music training disappear (Schellenberg et al. 2023). Thus, the way in which L2 ability is measured appears to play a role. Alternatively, the link with musical ability could be unreliable or context dependent.

When we asked more than 500 English-speaking undergraduates who took the MET about their language background (Swaminathan et al. 2021), self-reported proficiency in a tonal language correlated with melody-discrimination skills but not with rhythm discrimination. A recent meta-analysis confirmed that this result generalizes to native speakers of tonal languages (Liu et al. 2023). Liu et al. also reported new findings from a large web-based study with almost a half-million participants. They again found that tonal-language use was correlated positively with melody discrimination, but correlated negatively with beat perception.

More generally, different aspects of musical ability appear to be relevant for different languages and different L2s. For example, melody discrimination predicts German 9- and 10-year-olds' ability to imitate the pronunciation of Chinese words, whereas rhythm ability is a better predictor of the same children's ability to imitate Tagalog words (Christiner et al. 2018). For nonmusicians, discriminating words from an unfamiliar tonal language is superior if the listener already speaks two tonal languages rather than one (Toh et al. 2022). When musically untrained Italians segment continuous lowercase Spanish text into separate words, performance correlates with all subtests from the Mini-PROMS (melody, tuning, tempo, accent; Foncubierta et al. 2020). Among English-speaking nonmusicians, the ability to perceive and produce Mandarin words with different tones correlates with scores on a melody-discrimination test (Li & DeKeyser 2017). When English speakers are asked to learn Mandarin-like words with different tones, performance is predicted by pitch-processing abilities, general cognitive ability, and duration of music training (Bowles et al. 2016).

In one study of Italian 11- to 15-year-olds, however, musicians performed better than nonmusicians on an English-dictation task but not on a test of grammar, and musical ability was not associated with performance on either test (Talamini et al. 2018). Nevertheless, adding music (i.e., song perception/production) to a phonological-training program for Spanish 7- and 8-year-olds did not further improve L2 ability (Fonseca-Mora et al. 2015), which was instead correlated with their musical ability, although this association was fully mediated by L1 ability (Gomez-Dominguez et al. 2019).

In sum, associations between musical and L2 ability tend to be reliable, although the aspects of musical ability that are relevant vary across studies, the learners' language background, and the particular L2. Evidence for a special association with rhythm ability is inconsistent; melody discrimination is often a better predictor of L2 performance. We found no evidence that music training improves L2 ability and very limited evidence for a positive association.

GENERAL COGNITIVE ABILITIES

Memory

The meta-analysis by Talamini et al. (2017) of correlational studies concluded that musicians have enhanced STM, WM, and long-term memory (LTM). For STM and WM, the advantage was largest for tonal (music-like) stimuli, smaller for verbal stimuli, and negligible for visuospatial stimuli. For LTM, it was domain general. These conclusions do not inform the issue of causality. Although recent studies confirm that better performance on tests of memory is evident for musicians over nonmusicians, or for musically trained over untrained individuals (Alain et al. 2018, Albouy et al. 2017, Blain et al. 2022, Coffey et al. 2019, Correia et al. 2022a, D'Souza et al. 2018, Silas et al. 2022, Slater & Kraus 2016, Swaminathan et al. 2017, Talamini et al. 2022, Taylor & Dewhurst 2017, Yoo & Bidelman 2019), null results have also been reported (Hutka et al. 2015, Saarikivi et al. 2016, Strong 2022, Tierney et al. 2015, Tremblay & Perron 2023, Vanden Bosch der Nederlanden et al. 2020). In one instance, musicians exhibited an advantage in memory for classical music but not for pop music or lists of words (Wilbiks & Hutchins 2020).

Musical ability is also correlated with STM and WM (Swaminathan et al. 2021). In fact, associations with memory are sometimes evident for musical ability but not for music training (Swaminathan & Schellenberg 2018). In one instance, neither STM nor WM was associated with any subtest of musical ability in adulthood (Vanden Bosch der Nederlanden et al. 2020). In a study of 10-year-olds, rhythm-discrimination ability correlated with WM, whereas melody discrimination correlated with STM (James et al. 2020b). In a study of adults, auditory STM correlated with melody-discrimination abilities but not with two other subtests from the Mini-PROMS (tuning and tempo discrimination, $0.21 < r\text{s} < 0.40$), although the small sample ($N = 36$) was likely implicated in the null results (Talamini et al. 2016). Additional evidence comes from preschoolers, whose music-discrimination abilities were associated positively with STM (Christiner & Reiterer 2018, Degé et al. 2015), and from 6- to 9-year-olds, whose Digit Span scores were associated with musical ability but not with duration of music training (Swaminathan & Schellenberg 2020).

Recent longitudinal studies that focus on children or older adults provide little evidence that music training improves memory. For example, after 3- and 4-year-olds received 6 weeks of daily 30-min sessions in music or drama programs, both groups performed better than passive controls on one of two tests of WM (Kosokabe et al. 2021). For preschoolers who took 6 months of either piano or reading training, improvements on Digit Span were similar across groups (Nan et al. 2018). Moreover, when 5-year-olds received 6 months of twice-weekly music lessons, improvements in visual STM did not differ from controls (Bayanova et al. 2022). Jaschke et al. (2018) assigned entire school classes of 6-year-olds to a 2.5-year intervention that included music, visual arts, or no extracurricular training. Visuospatial STM and WM increased more for the visual arts group than for the music group. When another group of 6-year-olds received 20 weeks of 3 20-min sessions of sports training or either rhythm-based or pitch-based music training, visuospatial STM improved similarly across groups (Frischen et al. 2019).

Executive functions (EFs): domain-general cognitive abilities (e.g., inhibitory control) required for attention, problem solving, and flexible goal-oriented behavior

In other instances, positive results were limited to one or two memory tests from a larger battery, with no prior predictions about which tests should show effects (Bugos et al. 2022, Flaugnacco et al. 2015, Frischen et al. 2021, Guo et al. 2018, Holochwost et al. 2017). For each, the crucial interaction was weak ($0.01 < p < 0.05$) and uncorrected for multiple comparisons. In other "positive" results, the studies had minimal music training (4 hours; Price-Mohr & Price 2021), high dropout rates in the control group (Nie et al. 2022), or no interaction between group and time (James et al. 2020a).

In one study of nonmusicians in their 60s and 70s who received 8 weeks of music-rhythm or word-search training (Zanto et al. 2022), the music group had improved STM for faces, but the effect was small and there were fewer than 20 participants per group. For EEG responses, an interaction between group and time was evident only for the P3 (i.e., one of five EEG measures), which is difficult to interpret because group comparisons showed no differences between the music and control groups at pre- or posttraining. Although the study was preregistered, the selective P3 effect appears to be an exploratory result because planned analyses described neural correlates of temporal attention (measured by alpha activity and contingent negative variation), yet no such effects were observed. Other longitudinal studies of music training for seniors reported null results on tests of memory (Degé & Kerkovius 2018, Dubinsky et al. 2019, Johnson et al. 2020, MacAulay et al. 2019).

One retrospective study tested older adults' STM and LTM and asked whether performance was associated with playing music earlier in life, while holding constant high school IQ, educational achievement, sex, childhood SES, and previous stroke (Romeiser et al. 2021). Involvement in high school music predicted STM at age 65; this association decreased over the next 7 years, however, whereas playing music in adulthood had no association with STM. A different pattern emerged for LTM, which was associated with playing music in adulthood (and maintained over the next 7 years) but not with high school musical involvement. In any event, older adults with better memory could also be particularly likely to play music and to have good memory earlier in life.

In sum, musically trained individuals tend to have better memory than their musically untrained counterparts, but there is little evidence for causality, whether interventions are implemented early or later in life. In fact, we could not find a single convincing example that music training causes such associations. Memory tends to be associated positively with musical ability, however, which is consistent with the view that associations between music training and memory stem primarily from preexisting factors. Because same–different tasks used by musical-ability tests can be considered tests of auditory STM, it is unsurprising that musical ability correlates with other tests of auditory STM that use nonmusical stimuli (e.g., Digit Span).

Executive Functions

Executive functions (EFs) are the cognitive abilities for which an impact of music training makes the most intuitive sense. After all, playing music requires self-regulation, flexibility, attention, inhibitory control, and planning and implementation of goal-directed behaviors. In a recent review, most longitudinal studies of children (20 of 21) reported positive effects of music training on at least one EF, although other interventions could produce similar results (Degé & Frischen 2022). Moreover, interstudy variability was the norm, publication bias could not be ruled out, and positive findings were observed for inhibitory control, but they were weaker for other EFs, a conclusion seconded by another review (Rodriguez-Gomez & Talero-Gutiérrez 2022). A quantitative meta-analysis based on seven studies, some of which had no random assignment or active control groups, reported that music training improves EFs for children and adolescents (Román-Caballero et al. 2022). In an earlier meta-analysis on aging adults, four experimental studies yielded only a trend-level effect ($p = 0.057$) for flexibility, although correlational studies confirmed positive associations between music training and flexibility, attention, inhibition, and verbal fluency (Román-Caballero et al. 2018).

Recent correlational research reveals convoluted associations between musical expertise and EFs, with no obvious general trends, and positive findings that tend to be limited to one or two measures from large batteries of tests. Specific EFs under examination also vary across studies, as do tasks, terminologies, and whether SES and IQ are held constant. In one study, musicians had better sustained attention compared with nonmusicians and demonstrated faster performance, improved vigilance, and more consistent levels of alertness (Román-Caballero et al. 2021). IQ was not measured, however, and there were no effects for other EF tasks (attentional orienting and executive control). A previous study of attention, again not controlled for IQ, found no differences in the alerting and orienting systems, although musicians were better at directing attention to relevant information in the presence of distractions (Medina & Barraza 2019). Inhibitory control, which is typically assessed with Stroop, go/no-go, flanker, or Simon tasks, can have positive associations with music training among children (e.g., Frischen et al. 2022, Joret et al. 2017, Saarikivi et al. 2016), younger adults (e.g., Criscuolo et al. 2019, Okada & Slevc 2018), and older adults (e.g., Moussard et al. 2016, Strong & Mast 2019), although null results have also been reported (e.g., Boebinger et al. 2015, Clayton et al. 2016, D'Souza et al. 2018, Pentikäinen et al. 2021, Slevc et al. 2016).

Similarly inconsistent findings are observed on tasks that require task or set shifting, such as the Trail-Making Test or the Wisconsin Card Sorting Test. For example, when Frischen et al. (2022) assessed flexibility in adults and children with verbal and nonverbal set-shifting tasks, music training correlated with nonverbal but not with verbal set shifting for both age groups. Moradzadeh et al. (2015) also found reduced task-switching costs and improved dual-task performance in adult musicians compared with nonmusicians, which could not be explained by nonverbal IQ, age, SES, or bilingualism. Others reported null findings for set shifting (Clayton et al. 2016, Pentikäinen et al. 2021, Slevc et al. 2016), however, even when a latent variable was extracted from three set-shifting tasks (Okada & Slevc 2018).

Neural underpinnings of executive enhancements for musicians are similarly equivocal. In one EEG study with older adults and a visual go/no-go task, musicians had fewer errors on no-go trials compared with nonmusicians, but there were no differences on go trials or in response times (Moussard et al. 2016). For brain responses, group effects were null for the P1 and P2. For the N2, musicians had decreased amplitude for go trials, although latency did not differ between groups. For the P3, musicians had increased amplitudes for no-go trials at anterior sites, but again, latency did not differ between groups. In another EEG study, participants were musically trained and untrained 9- to 11-year-olds and 13- to 15-year-olds (Saarikivi et al. 2016). Although trained participants had better set-shifting and inhibition performance, age-related enhancements in neural auditory responding (MMN and P3 responses) were evident for trained and untrained participants, highlighting developmental differences that were independent of music lessons. In a late-adolescent sample (Saarikivi et al. 2023), functional MRI (fMRI) showed decreased activity for musically trained individuals in the dorsal attention network and the cerebellum during a set-shifting task, whereas EEG revealed distinct P3b responses, but the absence of behavioral advantages raises doubts about the relevance of the brain data.

Recent longitudinal studies reported mixed results regardless of age group. For example, when preschoolers took 19 weeks of music, motor-skills, or no training, the music group showed larger improvements in inhibition (Bolduc et al. 2021). When another group of preschoolers took 20 weeks of pitch- or rhythm-based music training or sports training, inhibition improved for the rhythm group, but there was no differential improvement for set shifting (Frischen et al. 2019). Other studies with active control groups failed to replicate effects on inhibitory control (e.g., Bowmer et al. 2018, Janus et al. 2016, Linnavalli et al. 2018). Bugos & DeMarie (2017) reported a positive effect of music training compared with Lego training on a test of inhibition that required visual discrimination and motor responses, but the two-way (group × time) interaction was driven by unexpected declines for the control group, there were no effects on a Stroop task, and the sample was small ($n < 20$ per group). Similarly, Degé et al. (2022) reported a positive effect of music training compared with sports training on inhibition in a sample of 25 preschoolers, but an uninterpretable decrease in performance for the sports group played a role in the two-way (group × time) interaction. Unsurprisingly, positive results emerged from studies without active controls (Hallberg et al. 2017, Shen et al. 2019). In one instance, however, eight weeks of training gave rise to a significant two-way (group × time) interaction on one of six measures (Stroop) because the music group got *worse* over time (Bowmer et al. 2018).

When Guo et al. (2018) randomly assigned 6- to 8-year-olds to music-training or passive control groups, there was no group difference for changes in inhibitory control. In a longitudinal study with self-selection into music (El Sistema–inspired) or sports training and a passive control group, comparisons of incongruent and congruent trials in a Stroop task showed that, in the second year, the music group had greater differential neural activity in the bilateral inferior frontal gyrus, supplementary motor area, cingulate, precentral gyrus, and insula (Habibi et al. 2018). These effects were not evident in behavior, limited to comparisons with passive controls, and correlational because the Stroop task was not included at baseline. At year four, Stroop performance remained unchanged by music training, and there were no group-specific longitudinal changes in brain activity (no significant group × time interaction; Hennessy et al. 2019). For the flanker test, only the music group improved in year 3 and 4 but this effect appeared to be driven by good baseline performance for controls. For delayed gratification, music training improved performance in one of two conditions in year 3 but the advantage disappeared in year 4.

Other studies with school-age children reported either null effects on EFs (D'Souza & Wiseheart 2018) or effects in a minority of conditions. For example, when children were assigned randomly to a music, arts, or control group, there were no effects of music training on measures of set shifting, fluency, or planning (Frischen et al. 2021). The music group improved more over time compared to controls in selective attention, but the two groups remained equivalent at posttest. A clearer effect was evident for inhibition but uncorrected for multiple comparisons. When other children were assigned to orchestra classes or regular music-listening education, improvement over time did not differ between groups on a test of attention (James et al. 2020a). Although the orchestra group improved more for processing speed and flexibility, the control group had higher performance at baseline. Jaschke et al. (2018) also reported positive effects from a music intervention on planning and inhibition but effects were small and uncorrected for multiple comparisons.

For healthy-aging older adults, comparisons of choir participants to passive controls had null results for a flanker test after 10 weeks of training (Dubinsky et al. 2019), and for flanker and trail-making tests after 44 weeks (Johnson et al. 2020). In a small-sample 3-month study, performance improvements on a go/no-go task did not differ between music and visual-arts groups, and differences in theta-power (indexing response suppression) were weak (lowest $p = 0.043$) and uncorrected for multiple comparisons (Lu et al. 2022). When older adults were assigned randomly to piano, cognitive, or no training, the piano group had larger improvement on a test of verbal fluency but not on tests of processing speed and inhibition (Bugos & Wang 2022). Dropout was over 30% in the cognitive group, however, and 44% of participants in the music group were excluded from the analysis. In a study with no controls, group singing improved verbal fluency but not processing speed or set shifting (Fu et al. 2018).

In a preregistered study (Nandi et al. 2023), older adults were assigned randomly to 8 weeks of rhythm or word-search training. The rhythm group improved more on a task that required them to tap on or off the beat to auditory, visual, or auditory-visual stimuli. Benefits were restricted to reductions in tapping variability, not actual synchronization, and to slow and medium but not fast tempi. EEG revealed that benefits in tapping behavior were accompanied by increased intertrial coherence for the delta band, consistent with the possibility that rhythm training improved sensorimotor timing. Effects were null for the other frequency bands and for analyses on event-related spectral perturbations, and rhythm training had no effect on visual-discrimination performance.

Some studies have been conducted with clinical samples. For Parkinson's patients who took 10 days of intensive piano training or no training, the piano group had fewer errors on a Stroop test in absolute terms, but no test of the two-way (group × time) interaction was reported, and there were no differences in improvement on tests of processing speed, set shifting, or verbal fluency (Bugos et al. 2021). When older adults (some with cognitive impairment) were assigned to music training or gymnastic activities, advantages for music training were reported for verbal fluency but not for attention and processing speed, again without a two-way (group × time) interaction (Biasutti & Mangiacotti 2018). In one instance, stroke patients improved slightly more after music training compared with physical activities on the trail-making test (group × time interaction, $p = 0.041$), but the advantage did not extend to verbal fluency, and there was no correction for multiple comparisons (Fujioka et al. 2018).

In sum, although many studies examined links between music training and EFs, there is no good evidence of causality for children or older adults, whether samples are typical or clinical. This conclusion is consistent with recent meta-analytic evidence showing that nonmusical forms of cognitive experiences (e.g., bilingualism) do not improve EFs (Lehtonen et al. 2018) and that there is no transfer between different EFs (Kassai et al. 2019). In some instances, music training is associated with performance on EF tasks, but we could not identify any clear and reliable response patterns.

Intelligence and Academic Achievement

An article from 20 years ago reported that random assignment of 6-year-olds to one year of music, drama, or no training increased full-scale IQ more for the music children compared with those assigned to the other groups (Schellenberg 2004). Nevertheless, a subsequent study with a much larger sample of 6- to 7-year-olds asked whether music and drama training influence school grades and reported null findings (Haywood et al. 2015). Moreover, recent meta-analyses including several cognitive and academic outcomes concluded that music training has effects only when studies have passive control groups and/or no random assignment (Cooper 2020, Sala & Gobet 2020a). Bigand & Tillmann (2022) reanalyzed the studies included in Sala & Gobet (2020a) and reached a different conclusion: Music training may indeed produce small yet significant far-transfer effects. In any event, if such effects exist they are likely to be small. Román-Caballero et al. (2022) also reported a positive effect but noted that well-designed studies are scarce.

Correlational studies often report associations between music training and general cognitive ability (Romeiser et al. 2021; Swaminathan & Schellenberg 2018, 2020; Swaminathan et al. 2018), although such associations are less likely when sample sizes are small (e.g., Hutka et al. 2015). Inclusion of professional musicians also reduces the odds of finding an association (Vincenzi et al. 2022) and could account for some inconsistency across studies. In one study of college students who took a large battery of tests, latent variables were formed for general cognitive ability, auditory ability, and music training (Silvia et al. 2016). Music training correlated strongly with intelligence and moderately but independently with auditory ability, two associations that parallel the two genetic factors associated with musical ability (Mosing et al. 2014b).

In our laboratory, we replicated the association between music training and general cognitive ability among 133 undergraduates who also took a test of musical ability (Swaminathan et al. 2017). The cognitive test was Raven's Advanced Progressive Matrices. Music training correlated with both cognitive and musical abilities, but the association between training and cognition disappeared when musical ability was held constant. By contrast, musical ability remained correlated with cognition when training was held constant. Thus, the link between music training and cognitive ability appears to arise because high-functioning individuals with high levels of musical ability are also more likely to take music lessons. In line with this view, when Hungarian children were followed from first to seventh grade, first-grade musical ability was associated positively with first-grade cognitive ability as well as with seventh-grade school performance (i.e., grade point average), even when cognitive ability and SES were held constant (Janurik & Józsa 2022). The association between school performance and musical ability stemmed from rhythm-related rather than melody-related skills, a finding consistent with others showing a stronger association with cognitive abilities for rhythm than for melody (Correia et al. 2022b, Swaminathan et al. 2021).

In a sample of Portuguese seventh to ninth graders with six or more years of music training or no training, the music group was reported to have higher general intelligence and SES six years earlier (dos Santos-Luiz et al. 2016). At both time points, the music group also demonstrated higher grades in school, and the difference grew larger over time. Similar results were evident at ages 11 and 16 in a sample of students from the United Kingdom: At both time points, grades were higher in English and mathematics for students who had learned to play a musical instrument (Baker et al. 2023). In other words, high-functioning individuals appear to do well in school and to take music lessons, and their intellectual advantages may grow larger over time. The same interpretation can explain associations that were evident in a sample of more than 100,000 high school students (Guhn et al. 2020). Taking music courses correlated with tenth-grade achievement in mathematics and science and with tenth- and twelfth-grade achievement in English, even when SES and seventh-grade academic achievement were held constant. In a smaller-scale study of 10- and 11-year-olds, duration of music training correlated positively with academic achievement in mathematics, Chinese, and English (Tai et al. 2018). Indeed, children who study music sometimes receive higher grades in school than one would predict from their IQs (Schellenberg 2006). This association disappears, however, when individual differences in conscientiousness are also held constant (Corrigall et al. 2013).

Okely et al. (2022) asked 82-year-olds about their lifetime musical activities, which were correlated positively with IQ tested previously at 11 and 70 years of age. Playing music also predicted increases in IQ from age 11 to 70, even with education, occupation, and health problems held constant, although such changes were smaller for individuals with higher IQs at age 11, presumably due to ceiling effects or regression to the mean. In another study of sixth- and seventh-grade students, half of whom opted to receive an additional three hours of weekly music training for one year, the group who received extra music training had higher cognitive ability compared with controls at study onset, but this difference did not change over the year (Carioti et al. 2019).

What does recent evidence tell us about a causal role for music training? Holochwost et al. (2017) used a lottery to assign low-SES first to eighth graders to an El Sistema–inspired music program that met for two hours daily. The control group comprised children who did not win the lottery. After two years, the music group had higher scores in mathematics and English and on standardized tests of academic ability. Although these findings are impressive, equally intensive but nonmusical interventions could produce the same effect. In another study of 10- to

12-year-olds (James et al. 2020a), scores on a test of matrix reasoning (a proxy for *g*) were higher for the active-music than for the music-listening group ($p = 0.033$) after 1 year of the intervention, but there was no additional benefit after 2 years and no correction for multiple comparisons, and the study had 16 dependent variables.

Null results tend to be the norm otherwise. For example, when 4- to 6-year-olds were assigned randomly to 10 weeks of multimodal-music or Lego training, or to a passive control group, change over time on two IQ subtests was similar across groups (Bugos et al. 2022). Other longitudinal studies of children with active control groups reported similarly null findings (D'Souza & Wiseheart 2018, Flaugnacco et al. 2015, Nan et al. 2018, Nie et al. 2022). Even with a passive control group, a one-year extended music program failed to enhance the IQ of 9- to 11-year-olds (Degé & Schwarzer 2018). For studies with no control group, however, reports of increases in general cognitive ability are more common (Barbaroux et al. 2019, MacAulay et al. 2019, Osborne et al. 2016, Ribeiro & Santos 2017).

In short, positive associations between music training and general cognitive ability are relatively common, but there is little evidence that music training is a causal factor. The available data also suggest that when musical ability is measured at the same time as music training, ability rather than training may account for such associations.

SOCIAL-EMOTIONAL FUNCTIONING

Interpersonal synchrony promotes affiliative and prosocial behaviors from infancy to adulthood (Cirelli 2018, Rennung & Göritz 2016). For example, bouncing a toddler to music and in synchrony with a confederate increases the likelihood that the toddler will subsequently help the confederate (Cirelli et al. 2014). Such increases extend to the confederate's friends, as demonstrated to toddlers in a video they see before bouncing (Cirelli et al. 2016). The same effects emerge at 14 months without music, however, although helping behavior is delayed and the infants are fussier (Cirelli et al. 2017). Synchronous movement in the absence of music also influences the social choices of 12-month-olds (Tunçgenç et al. 2015). Perhaps moving synchronously signals group membership (Cirelli 2018). In any event, moving in synchrony with someone else requires a partner or partners but not necessarily music. In our view, group music making may be key for improving well-being, social skills, and affiliative behaviors. Open questions are whether music is essential for such effects to emerge and whether these noncognitive effects represent actual transfer. Review articles confirm that social-emotional benefits of music training remain poorly understood (Campayo-Muñoz & Cabedo-Mas 2017, Crooke et al. 2016, Martins et al. 2021).

In another study, 18-month-olds were assigned to 4 min of a joint music-making activity with an experimenter (Buren et al. 2021a). Subsequent helping behavior toward the experimenter increased compared with control conditions that involved listening to music or joint reading. Music making with infants may also have long-term positive consequences. For example, when parents of young children were asked about their experiences during the COVID-19 pandemic, parent–child musical activities were associated positively with parent–child attachment, even when parental distress, efficacy, and education and nonmusical activities were held constant (Steinberg et al. 2021). Alternatively, good parent–child relationships could increase the likelihood of making music together.

In a correlational study with adults, researchers asked whether musical expertise was associated positively with the quality of interpersonal relationships (MacDonald & Wilbiks 2022). The participants comprised ~200 undergraduates who completed a self-report measure of musical sophistication (Müllensiefen et al. 2014) and the Quality of Relationship Inventory (Pierce et al. 1997), which has subscales for support, conflict, and depth. Music training had no association with any aspect of relationship quality, but higher self-reports of music-perception abilities predicted reduced conflict in relationships. A similar association was not evident for support or depth, but the correlation with conflict was strong enough ($p = 0.005$) to withstand correction for multiple tests. Nevertheless, extraneous differences associated with musical ability (e.g., personality) could explain this link.

In a longitudinal study conducted at two different schools, 10-year-olds enrolled in El Sistema–inspired programs were tested and compared with children from the same school, and then they were retested a year later on eight measures of social functioning and well-being (Osborne et al. 2016). At one school, there were no group differences at either time point. At the other school, children in the music program scored higher on all measures at the beginning of the year, perhaps due to their previous involvement with El Sistema, although they did not improve more than controls over the year on any measure. Alemán et al. (2017) asked whether El Sistema has positive effects on the development of children in Venezuela, where the program originated. Almost 3,000 6- to 14-year-olds were included, with approximately half entering the program one year earlier than the other half. Behavioral problems decreased more for the early-admission group, who also improved in self-control. These effects were exaggerated among lower-SES children and for boys, particularly those with a history of violence, who also exhibited decreases in aggressive behavior. Whether similar results would emerge in cultures with less social turmoil is unknown.

Choir singing requires behavioral synchrony, which could, in turn, drive social or emotional benefits. Indeed, when Johnson et al. (2020) assigned older adults to a choir for 6 months or to a wait-list control group, reductions in loneliness and increases in interest-in-life were greater for the choir participants. Another group of older adults was assigned at random to a gymnastics-training control group or to 12 sessions of a group music-training program that was designed to facilitate social interactions (Biasutti & Mangiacotti 2021). Improvements in depressed mood were evident only for the music group. In yet another study, however, improvements in well-being were similar for older adults who participated in choir or exercise groups for 7 months (Maury & Rickard 2022). Although older adults with high levels of self-reported choir activity also provide higher self-reports of social integration (Pentikäinen et al. 2021), individuals with larger circles of friends may simply be more likely to sing in choirs. A study of college students who took 4 weekly 1-hour sessions of choir practice reported reductions in stress, as evidenced by decreases in salivary cortisol and self-reports (Taets et al. 2021). There was no control group, however, and only 4 of 25 participants were men. In another study without controls, a single 90-min session of choir singing increased feelings of social connectedness, inclusion, positive affect, and endorphins, even in a large-group context where participants were unfamiliar with one another (Weinstein et al. 2016).

In our longitudinal study of instrumental music training, 8- and 9-year-olds took 10 months of weekly 40-min group ukulele lessons (Schellenberg et al. 2015). Compared with a control group of age- and SES-matched children, improvements from pre- to postlessons were higher for children in the music group on measures of prosocial skills and sympathy, but only for the children who scored low on these measures at the beginning of the study. High scorers presumably had little room for improvement. The findings did not change when the music group was limited to children who had no choice about participating in the ukulele lessons, which suggests that self-selection was not driving the effects, although other group activities could have similar social benefits.

Degé & Schwarzer (2018) assigned 9- to 11-year-olds to an extended music program that consisted of two additional music classes per week, one in groups, as well as weekly participation in a school choir or orchestra. The children exhibited pre- to postintervention improvements in academic self-esteem that were greater than those demonstrated in children without the additional music classes. A study of children with cleft lip or palate also reported that music training improved well-being, although there was no control group (van der Weijden et al. 2023). For young Japanese children who studied at a music school, earlier onset of music training predicted higher levels of empathy, communication, and extraversion (Kawase et al. 2018). As in Corrigall & Schellenberg (2015), children's early participation in music was primarily a parental decision. Taking a young child to group music lessons also improves parents' mood and reduces anxiety (Kawase & Ogawa 2020).

A review by Sihvonen et al. (2017) of rehabilitation programs for neurological conditions (e.g., stroke, dementia, Parkinson's, epilepsy, multiple sclerosis) concluded that music-based interventions are promising but that more controlled studies are needed to confirm their efficacy. In one example, reductions in depression for elderly individuals with dementia were greater after a six-month intervention that included choir singing instead of group music therapy (Baker et al. 2022). In another example, patients with acquired brain injury and chronic aphasia were tested in a crossover design with random assignment, such that they received standard care either before or after a 16-week intervention that included weekly group singing, melodic-intonation therapy, and singing training at home (Siponkoski et al. 2023). The music intervention enhanced social participation and reduced caregiver burden in addition to improving communication skills. Even children with hearing loss may exhibit psychosocial benefits and improvements in well-being after group music training (Lo et al. 2022).

In short, some evidence suggests that group music making has social-emotional benefits, particularly when interventions for clinical and atypically developing participants include music. When musical ability is associated with social-emotional functioning, extraneous individual differences (e.g., personality) are likely to be implicated.

CONCLUSION

The possibility that music training enhances cognition has stimulated research programs, informed public policy, and made enthusiastic headlines in the media. Indeed, the idea that music is good for brains and cognitive abilities has become folk wisdom. Mission statements from projects for disadvantaged youth reflect this view: "Our program was developed using cutting-edge arts education research to maximize the positive, long-term effects of music engagement, including increased focus, academic success, and cognitive ability" (Harmon. Proj. 2019).

But what does the evidence tell us? Although musically trained individuals tend to have enhanced listening skills, evidence that music training causes the enhancements is very limited. If listening skills are normally distributed like most human attributes, as they appear to be (Swaminathan et al. 2021), individuals with poor skills would be unlikely to pursue music training, thereby guaranteeing a positive association. Perhaps the music interventions are too brief, although six months is a relatively long time for a preschooler (e.g., Nan et al. 2018). In any event, results are even more pessimistic for SIN and prosody perception: Music training and musical ability correlate with performance, but there is no good evidence for a causal training effect. The same pattern—positive associations but weak or no evidence for causation—extends to other domains of language and to general cognitive abilities. In short, the available evidence can be explained parsimoniously without resorting to claims of far transfer that lack theoretical motivation and contradict decades of studies of human behavior. High-functioning individuals and/or those with good listening skills are also more likely to study music.

Although positive findings from individual studies are reported frequently, meta-analyses show that far transfer from music training is small or nonexistent (Bigand & Tillmann 2022; Cooper 2020; Neves et al. 2022; Román-Caballero et al. 2022; Sala & Gobet 2017a,b; Sala & Gobet 2020a). Moreover, findings from longitudinal studies vary across samples, study designs, and tasks, often for unclear reasons, raising doubts about reliability and generalizability. In principle, well-controlled experimental studies could clarify the issue of causality. In practice, increased control is accompanied by decreased ecological validity. Researchers, ourselves included, speak of music training as if it is tangible and unidimensional, yet playing the piano is very different from singing in a choir; likewise, anyone who has had more than one music teacher knows that changing from one teacher to another can be like night and day.

Consider the admirable study of children with dyslexia (Flaugnacco et al. 2015). The focus on rhythm meant that the intervention was not about music training per se, but about addressing temporal-processing difficulties with an intervention that incorporated aspects of music. Similarly, El Sistema may improve the lives of disadvantaged children, but many nonmusical aspects of the program could account for its success, and finding a comparable control activity that maintains a child's interest is difficult. A passive control group may not matter to policy makers—if something works, it works—but the goal of psychology and neuroscience is to understand if it works and why it works (Bishop & Thompson 2023).

The cost and difficulty of implementing longitudinal studies (Habibi et al. 2022) also mean that these studies tend to have small samples, such that both positive and negative results are difficult to interpret. Another problematic assumption is that short-term interventions—lasting a few months with one or two sessions per week—produce systematic changes in brain and behavior comparable to those observed in musicians with many years of experience. Because 5- or 10-year controlled interventions are impossible due to differential attrition, we question whether longitudinal studies can reveal meaningful consequences of music training. A further complicating factor is that random assignment is likely to be accompanied by greater attrition and lower motivation, engagement, and practice, which would minimize training effects. Random assignment creates other problems; we know this firsthand because it typically requires researchers to provide music training for free. For example, when parents were asked about their child's weekly practice at the end of Schellenberg's (2004) study, the typical response was 10–15 min. In short, a perfect study from an experimental-design perspective is likely to be so artificial that the results would tell us little about how people engage with music in real life and how interventions could be implemented. Efforts to address these problems are commendable (e.g., Habibi et al. 2022, Papatzikis et al. 2023, Tervaniemi 2023), but the answers are not obvious.

Our own strategy was to shift to large-scale correlational studies. Although correlations cannot prove causation, claims of causation require correlations. After all, if a causal effect is not evident in the real world, it is simply a laboratory phenomenon. In our view, studying naturally occurring variation in music training, combined with measures of individual differences including musical ability, provides important information about interactions between genes and the environment, specifically preexisting differences that increase or decrease the likelihood of music training and its associations with nonmusical variables.

The music-training literature also suffers from issues raised by the reproducibility movement in psychology and neuroscience (Munafò et al. 2017, Nosek et al. 2022, Poldrack et al. 2017), including low statistical power, flexible data analysis and reporting, liberal statistical thresholding, piecemeal publication, confirmation bias, lack of direct and independent replications, insufficient details about training regimens, and failure to distinguish planned from exploratory analyses (Bishop & Thompson 2023). Authors often include multiple measures to increase the odds of finding something, only to overinterpret positive results while overlooking negative ones, a problem exacerbated by failing to correct for multiple comparisons. These issues extend to summaries of the literature and lead to unexplained variability in meta-analyses (e.g., Neves et al. 2022, Román-Caballero et al. 2022, Sala & Gobet 2020a). Although some methods help to identify and quantify publication bias, they have limitations (e.g., Stanley 2017) that preclude unequivocal interpretations. Indeed, divergent findings from recent meta-analyses (e.g., Román-Caballero et al. 2022 versus Sala & Gobet 2020a versus Bigand & Tillmann 2022) arise not only because their foci differ, but also because of the problems within the studies included. Specifically, effect sizes from longitudinal studies that we deemed to be uninformative (e.g., Bugos & Wang 2022, James et al. 2020a, Tierney et al. 2015) contribute to "positive" meta-analytical findings. In other words, the quality of a meta-analysis cannot be better than the average quality of the studies it includes.

These issues also need to be contextualized at a higher level. Funding agencies increasingly emphasize applied research, such that cognitive, educational, and clinical benefits of music training are attractive propositions. From the perspective of publication practices and incentives, positive results and clear narratives are easier to publish than are negative results or replications (Munafò et al. 2017). These systemic biases may explain why researchers often report selective benefits of music training while overlooking negative results. Changes have been suggested and implemented (e.g., Chambers & Tzavella 2022, Nosek et al. 2015) to improve publication practices, but their impact will take time to become manifest.

A related problem is journal quality. On the one hand, our list of citations has an inordinate number of articles published in open-access journals with peer-review practices that are motivated by profit and often short of rigorous. On the other hand, high-impact journals do not guarantee quality research, and requirements of novelty and impact encourage overinterpretation. Some of these problems could be addressed by better-quality research and acknowledgment that absence of an effect does not prove the null hypothesis. This issue is especially problematic when musically trained and untrained individuals are claimed to score similarly on extraneous measures that could influence the results (e.g., IQ), but the null finding (e.g., $p = 0.07$) is likely to be significant with a larger sample.

If music training were to have far-transfer effects, how long would such effects last, and what are the neurocognitive mechanisms at play? One article, published in the *Annual Review of Psychology*, claimed, based on correlational data, that "just a few years of musical training in childhood can influence the neural encoding of sound in adulthood, years after the training has ceased" (Kraus & Slater 2016, p. 96), which seems unlikely considering the evidence reviewed here. Although Patel (2011, 2012, 2014) provides a mechanistic account for transfer from music to speech perception, most studies fail to specify which aspects of music training lead to transfer and why. Indeed, the variety of interventions implemented across studies precludes a critical analysis of the components that are likely to matter. These problems are intensified by evidence of distinct profiles of sensorimotor brain responses for different types of music training (e.g., beatboxing versus guitar playing; Krishnan et al. 2018) and by differences between professional musicians and musically trained nonprofessionals in terms of personality and cognitive ability (Vincenzi et al. 2022). Moreover, formal music lessons, musical ability, and informal musical experiences have similar correlates (Correia et al. 2023).

As a way forward, recommendations from the reproducibility movement could be implemented in terms of planning, methods, analyses, reporting, and open-science practices. Because reliable far-transfer effects are unlikely, focusing on near transfer is likely to be more fruitful. Tailored music-based interventions for atypical populations, such as those with cochlear implants or neurodevelopmental, acquired, or degenerative conditions, also appear promising, even if only because there is more room for improvement when performance levels are low at the outset. Nevertheless, to be theoretically meaningful, the design of interventions needs to be constrained by the goals to be achieved, with the hypothesized mechanisms made explicit.

To clarify, our pessimistic view of far transfer is not at odds with promising findings regarding the use of music in health care, which range from pain management and anxiety reduction during surgical procedures to interventions for psychiatric and neurological disorders such as Alzheimer's disease (e.g., Jespersen et al. 2022, Matziorinis & Koelsch 2022). Many of these effects rely on the social and emotional powers of music, which are undeniable and universal (Koelsch 2014, Swaminathan & Schellenberg 2015) and do not depend on years of formal practice and tenuous links between music lessons and nonmusical abilities. In other words, redirecting research efforts to music itself and its core functions—bringing people together, eliciting and regulating emotions, and linking sound to movement—might be more productive than pursuing elusive perceptual or cognitive side effects of music lessons, which are not what move people toward music.

In conclusion, music training is not a good model of plasticity (e.g., Herholz & Zatorre 2012, Moreno & Bidelman 2014, Schlaug 2015) because musically trained and untrained individuals differ in many extraneous ways, duration of training correlates with such differences, professional musicians have different profiles than do musically trained nonprofessionals, and individuals with no training but high levels of musical ability are similar in many respects to highly trained individuals. Moreover, genetic and nonmusical environmental factors play important roles in the development of musicality, in the determination of who engages and persists in music lessons, and in associations between musical and nonmusical abilities. Accordingly, plasticity and transfer cannot be presumed to explain nonmusical differences observed in cross-sectional comparisons between musically trained and untrained individuals or in longitudinal studies without random assignment. When we consider the accumulated evidence as a whole, music training does not have systematic and generalizable far-transfer effects to any cognitive domain, in line with null findings observed for other training regimens.

Some researchers argue that nonmusical consequences of music training help to justify the inclusion of music in public education (e.g., Barbaroux et al. 2019, Kraus & White-Schwoch 2020). Arguing for music's by-products tacitly implies, however, that if the proposed causal links prove to be spurious, as we have shown, administrators focused on STEM (science, technology, engineering, and mathematics) can cut music programs willy-nilly. In our view, it is more useful to argue for music's inclusion in school curricula and funded research because of its intrinsic value. As Sandra Trehub (personal communication) once noted, Isn't it reasonable to teach kids about the only thing that makes people everywhere dance, dream, and connect with one another?

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