

Music and Nonmusical Abilities

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ABSTRACT: Reports that exposure to music causes benefits in nonmusical domains have received widespread attention in the mainstream media. Such reports have also influenced public policy. The so-called “Mozart effect” actually refers to two relatively distinct phenomena. One concerns short-term increases in spatial abilities that are said to occur from listening to music composed by Mozart. The other refers to the possibility that formal training in music yields nonmusical benefits. A review of the relevant findings indicates that the short-term effect is small and unreliable. Moreover, when it is evident, it can be explained by between-condition differences in the listener’s mood or levels of cognitive arousal. By contrast, the effect of music lessons on nonmusical aspects of cognitive development is still an open question. Several studies have reported positive associations between formal music lessons and abilities in nonmusical (e.g., linguistic, mathematical, and spatial) domains. Nonetheless, compelling evidence for a causal link remains elusive.

KEYWORDS: Musical ability; Music exposure; Mozart effect; Spatial ability; Nonmusical benefits of music training

INTRODUCTION

The present report evaluates claims that exposure to music produces benefits in nonmusical domains. These claims began to influence public policy as soon as they came to public notice.¹ For example, Zell Miller, the former Governor of Georgia, budgeted for the distribution of classical music recordings to each infant born in state. Moreover, Florida mandates daily doses of classical music in state-run pre-schools.

Researchers² and journalists^{3–6} have generated confusion by failing to clarify the distinction between the short-term consequences of music listening and the long-term consequences of formal training in music. Indeed, results from both types of studies have been merged to yield the dictum, “music makes you smarter.” However, passive listening to music, a ubiquitous activity, bears little resemblance to formal training, which involves lessons and systematic practice. Thus, separate evaluation of the short-term benefits of musical exposure and the long-term side effects of music lessons could help to clarify these issues.

Examination of the effects of previous experience on learning and behavior has a rich tradition in the history of psychology. “The *transfer* of training from old to new

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situations is part and parcel of most, if not all, learning. In this sense the study of transfer is coextensive with the investigation of learning”⁷ (p. 1019; emphasis added). In addition, hundreds of psychological examinations of *priming* have investigated how prior exposure to a stimulus affects subsequent processing of the same stimulus or a closely related stimulus.⁸ If exposure to music causes welcome side effects, we would expect such effects to arise from transfer or priming. Moreover, some researchers who argue for the nonmusical benefits of exposure posit a specific neuropsychological basis for such benefits.^{2,10–12} Presumably, this hypothesized cortical process would be compatible with other cortical processes that are demonstrably relevant to music.

TRANSFER AND PRIMING

Transfer and priming occur in positive and negative forms. Positive transfer occurs when previous experience in problem solving makes it easier to solve a new problem,^{7,13} typically by accelerating learning. As such, positive transfer describes successful generalization of a process or strategy. One example involves reasoning with analogies.¹⁴ Previous exposure to analogies can lead to greater success at finding the missing piece in new analogies (e.g., *Lawyer* is to *client* as *doctor* is to ???; the correct answer is *patient*). Similar research is available on metaphor and the transfer of skills.¹³ A common theme across transfer effects is *similarity*;^{13,15} positive transfer is more likely to occur when there are more similarities between the old and new problems.

Negative transfer is the opposite of its positive counterpart; previous experience interferes with solving a new problem.⁷ Negative transfer, which is often called *interference*, can occur proactively or retroactively. Proactive interference is evident when previous learning makes subsequent learning relatively difficult. For example, a new problem is approached with an old mental set that is inefficient or inappropriate for the new context. By contrast, retroactive interference refers to difficulty accessing mental representations because of intervening experience between initial encoding and retrieval.

Roughly speaking, priming can be considered the “short-term” or “low-level” relative of transfer. Anderson¹⁶ defines priming as “an enhancement of the processing of a stimulus as a function of prior exposure” (p. 459). In a classic experiment,¹⁷ participants were asked to identify words presented briefly in the visual modality. Performance was superior for words that were seen prior to the word-identification test. The low-level nature of priming is evident in greater priming effects following open-ended instructions (e.g., study the word) compared to compulsory semantic processing (e.g., generate an antonym), the latter condition involving “deeper” levels of processing.¹⁸ It is clear that priming does not require conscious awareness, as reflected in the priming effects observed in amnesics.¹⁹

Negative priming refers to situations in which the processing of a “target” stimulus is *inhibited* by prior exposure.²⁰ For example, when participants are presented with two words (a “target” and a “distractor”) and required to name only one (the target), performance on subsequent trials is relatively slow when the target word was previously a distractor. Most priming studies examine *repetition* priming, or subsequent processing of an identical stimulus.⁸ Nonetheless, cross-modal and cross-lan-

guage priming effects are also observable. For people who are bilingual in Spanish–English, auditory presentation of a partial sentence in Spanish (the priming stimulus) can facilitate visual recognition of a target English word, provided that the target was implied by the sentential prime.²¹ There are higher-level, *associative*¹⁶ or *semantic*⁹ priming effects, in which word processing (e.g., butter) is facilitated by previous presentation of an associated word (e.g., bread).²²

This brief review of transfer and priming provides a context for evaluating specific claims about exposure to music. These claims posit remarkable positive side effects of exposure to certain types of music, side effects that, in principle, are closely related to transfer and priming. My intention is to situate claims that *music makes you smarter* in the context of cognitive psychology, which will permit a review and evaluation of such claims with reference to well-established cognitive phenomena. A secondary goal is to situate the neuronal mechanism advanced as the basis of associations between music and nonmusical abilities in the domain of cognitive neuropsychology.

THE MOZART EFFECT

The current debate about musical exposure and its side effects was inspired, in part, by Rauscher *et al.*²³ who reported that brief exposure (10 minutes) to a Mozart sonata generates short-term increases in spatial-reasoning abilities (the *Mozart effect*). Each participant in their study was tested in three conditions. Participants in one condition listened to a Mozart sonata before completing one of three tests of spatial abilities. Participants in the other two conditions listened to a relaxation tape or sat in silence before completing a test. Performance was superior in the “Mozart” condition. This finding attracted considerable attention, because it appeared in a highly prestigious journal, *Nature*, and because the investigators translated their finding into an IQ-score improvement of approximately 8 points (i.e., half a standard deviation). Indeed, the popular conclusion that “music makes you smarter” followed directly from this IQ translation.

Closer examination of the method of that study raises questions about the validity of the findings. The choice of comparison conditions is particularly problematic. Sitting in silence or listening to a relaxation tape for 10 minutes is less arousing or interesting than is listening to Mozart. Moreover, mood states are known to influence performance on problem-solving tasks, with superior performance associated with positive affect.^{24–26} Thus, the effect could have arisen from differences in mood or arousal rather than from exposure to Mozart.

Because the Mozart effect is at odds with the literature on priming and transfer, alternative explanations of the source of the effect (i.e., the mood/arousal hypothesis) seem all the more credible. Improved spatial skills following exposure to a Mozart sonata do not represent an instance of repetition priming (i.e., the priming stimulus was not repeated) nor are they an instance of associative priming. How is passive listening to a musical stimulus “associated” with performance on a visually presented test of spatial skills? Evidence for associative priming typically involves pairs of words with an obvious semantic association (nurse–doctor, bread–butter). How, then, could an auditory (musical) stimulus prime performance on a task with no obvious link to music? Transfer as an explanatory framework also raises more

questions than it answers. Transfer typically involves applying a learned skill or a strategy to a new context. But what is learned by listening passively to a piece of music? Something about the music, no doubt, is learned, but it is difficult to rationalize how the transfer of such knowledge could yield improved performance on a spatial task.

In short, the Mozart effect is a radical claim about cognitive processes that is difficult to reconcile with known principles and findings in cognitive psychology. It comes as no surprise, then, that attempted replications have produced mixed results.^{10,27} As of May 2000, there were about 20 published tests of the Mozart effect. Less than half replicated the effect. Because the Mozart-effect studies have been reviewed elsewhere, the present report focuses on the issues raised by selected studies.

Consider the replication reported by Rauscher *et al.*,¹² who “pretested” their participants with a paper-folding-and-cutting (PF&C) test (one of the spatial tests used in the original study). Participants were then divided into three groups of equivalent abilities. One group heard Mozart during three subsequent test sessions. A second group sat in silence during the three sessions. A third group heard a minimalist piece by Philip Glass during the first session, an audiotaped story in the second session, and a repetitive piece of dance music in the third session. After each session, the PF&C test was administered again. Although the Mozart group showed a significantly larger improvement in performance than did the other two groups after the first session, there was no difference between the Mozart and comparison groups after the next two sessions. The advantage of Mozart over silence and Glass conditions in the first test session did not extend or clarify the original finding. Participants may find repetitive, minimalist music as boring or unarousing as silence. The null findings in the second and third sessions also raise doubts about the reliability of the effect.

Rauscher and Shaw¹⁰ suggest that the numerous replication failures can be explained primarily by differences in the spatial tasks that have been used as outcome measures. They claim that the effect can be obtained with “spatial-temporal” tasks (e.g., the PF&C task and other tasks involving mental transformation of visual images), but not with “spatial-recognition” tasks. This distinction is based on the idea that perceiving and remembering music involve identifying changes and systematic transformations in musical patterns (e.g., motives) that occur over time. Thus, transfer from music listening to the spatial domain should be limited to tasks involving mental manipulation of visual images, which also takes time. Indeed, the time required is linearly related to the amount of manipulation.²⁸ This distinction is curious in light of the original findings,²³ which indicated that the effect was identical across spatial tasks, temporal or otherwise. In a subsequent reanalysis of the original data,¹⁰ however, the advantage of the Mozart effect proved to be significant on only one of the three spatial tests that were administered, the “temporal” PF&C task, and not on the two nontemporal tests. Nonetheless, mean scores were highest in the Mozart condition across tests, and the design precluded tests of the two-way interaction between the listening conditions and the spatial tests. In other words, despite their conclusion and interpretation, the data did not support Rauscher and Shaw’s hypothesis, that is, that the influence of Mozart’s music on spatial abilities depends on the temporal nature of the tasks. Moreover, the temporal/nontemporal distinction cannot explain why several attempts to replicate the original findings failed to do so, even

though the outcome measure was a task that met Rauscher and Shaw's criteria for spatial-temporal status.^{29,30} Finally, the distinction does not address the problem that the effect, when evident, may be a consequence of differences in mood or in arousal.

In *all* cases in which the Mozart effect has been evident, comparison conditions involved repetitive music, sitting in silence, or listening to relaxation tapes. As noted, these comparison conditions might seem boring to participants (compared to listening to music), promoting relatively negative mood states or low levels of cognitive arousal. As a first attempt to address this possibility, Nantais and Schellenberg³¹ replicated and extended the original findings. In their first experiment, each participant was tested on the PF&C task twice, once after listening to 10 minutes of music and once after sitting in silence for 10 minutes. For some participants, the music was the same Mozart piece used by Rauscher and her colleagues. For others, a piece by Schubert (from the same compact disk performed by the same pianists) was used instead. This experiment was also the first to use a computer-controlled procedure administered to participants individually. Indeed, the potential impact of group dynamics on the results of earlier studies is unknown.^{12,23,29,32,33} (Imagine a classroom of undergraduates being required to sit in silence for 10 minutes!)

As shown in FIGURE 1 (upper panel), performance on the PF&C test was better after listening to Mozart than sitting in silence. In other words, the Mozart effect was replicated. Nonetheless, an identical effect was evident when the Mozart composition was substituted with the piece by Schubert (FIG. 1, middle panel). One would predict such a "Schubert effect" if the comparison condition (silence) was depressing levels of performance. For both groups, performance also improved from the first to the second testing session, revealing a simple practice effect. In a second experiment, a Mozart condition was contrasted with a comparison condition that involved listening to a narrated short story (potentially as engaging as listening to music) instead of sitting in silence. The Mozart effect disappeared (FIG. 1, lower panel), as one would predict if the experimental (Mozart) and comparison (story) conditions were equally engaging and if the source of the Mozart effect stemmed from differences in mood or arousal. Perhaps even more important was the finding that performance interacted with listeners' preferences. Those who preferred Mozart over the story performed better on the PF&C test after listening to Mozart. Those who preferred the story performed better after listening to the story (FIG. 2). These findings provide support for the suggestion that short-term effects of music on tests of spatial abilities stem from differences in mood or arousal rather than from listening to Mozart. Although the FIGURE implies that participants who preferred Mozart performed better regardless of condition, the main effect of preference was marginal ($p = 0.09$).

Further support for the "mood or arousal" hypothesis comes from a metaanalysis that provided an overview of 20 Mozart-silence comparisons conducted to date.²⁷ The overall advantage of listening to Mozart on subsequent tests of spatial skills was nonsignificant (i.e., equivalent to 1.4 IQ points). The effect size for studies that used a spatial-temporal outcome measure was also nonsignificant (2.1 IQ points) and smaller than the average test-retest variability in IQ for a single person. Moreover, successful replications of the Mozart effect were attributed to cognitive arousal, which is predominantly a right hemisphere function,³⁴⁻³⁶ as are tests of complex

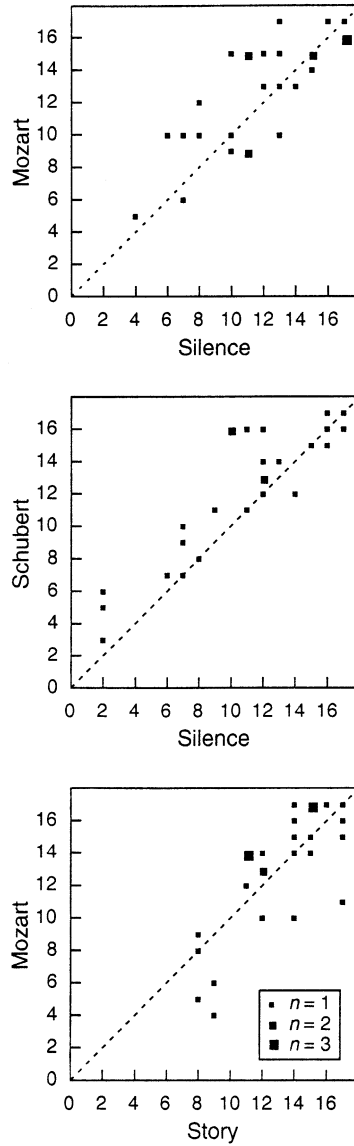


FIGURE 1. Scores on the paper-folding-and-cutting task for participants tested by Nantais and Schellenberg (1999). Each participant was tested twice. The *upper panel* illustrates scores after listening to Mozart or sitting in silence. The *middle panel* illustrates scores after listening to Schubert or sitting in silence. The *lower panel* illustrates scores after listening to Mozart or a narrated story. The line on the *diagonal* represents equivalent performance across conditions. The maximum score was 17.

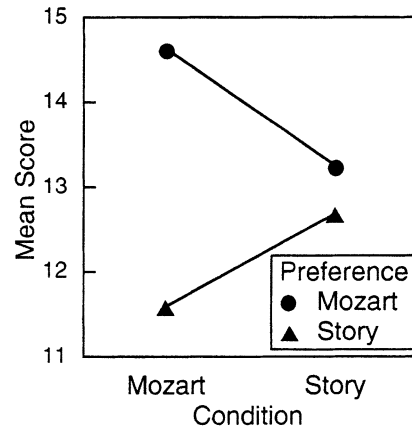


FIGURE 2. Scores from Nantais and Schellenberg's (1999) participants as a function of testing condition (Mozart or story) and preference (Mozart or story).

spatial abilities.^{36,37} This view helps to explain why the Mozart effect tends to be slightly larger when the control condition consists of relaxation instructions, which are designed to reduce arousal, instead of sitting in silence.²⁷

Another way to interpret the Mozart effect is provided by a new theory based on a large body of findings on the association between mood and cognition.³⁸ The theory proposes that positive mood states increase circulating levels of the neurotransmitter dopamine. During periods of positive affect, dopamine is released from the ventral tegmental area, which has projections to the prefrontal cortex. A variety of cognitive tasks that show improvement when positive affect is induced²⁵ may be influenced by the effects of dopamine on prefrontal function. It is possible, then, that the Mozart effect is another way in which positive affect influences performance in a problem-solving task. In short, although these seemingly mysterious effects of cross-modal priming (i.e., the Mozart effect) may indeed have a neuropsychological explanation, listening to music is just one of many ways to induce arousal or positive affect.

The metaanalysis presented by Chabris²⁷ and the results of Nantais and Schellenberg³⁰ are consistent with the idea that differences in mood or arousal are the actual source of the Mozart effect, but neither report tested this hypothesis directly. Thompson *et al.*³⁹ attempted such a test using the PF&C task as their outcome measure. Each of their participants was tested once in a music condition and once in a silence condition (as in Nantais and Schellenberg,³⁰ Experiment 1). Participants' mood after listening to the music was measured using the Profile of Mood States.⁴⁰ For some participants, the music condition consisted of the same Mozart piece used in the original Mozart-effect study; for others, a piece by Albinoni was used instead. The Albinoni *Adagio* was selected, because it is considered to be a stereotypical example of slow, sad-sounding music.⁴¹ By contrast, the Mozart sonata is pleasant and happy sounding. Hence, the prediction was that increases in performance on the PF&C task would be evident for music compared to silence in the Mozart group but not in the Albinoni group. This prediction was upheld by the data. Moreover, the per-

formance advantage of the music over the silence condition in the Mozart group disappeared when differences in participants' mood scores were partialled out of the analysis. In short, the results were completely consistent with the notion that the Mozart effect is an epiphenomenon of mood or arousal.

The theoretical framework that Rauscher and Shaw use to explain the Mozart effect is called the "Trion model."^{42,43} The model states that specific cortical firing patterns are present over large areas of the cortex when one performs, composes, or listens to music. Because these patterns are considered to be spatial-temporal in nature, they are said to be highly similar to patterns evident during spatial-temporal reasoning. Both processes involve perceiving and thinking about rule-governed transformations that occur over time. The model describes more than a simple associative or connectionist network, in which one group of neurons is connected to another group. Rather, it posits actual similarities in cortical firing patterns for (1) passive listening to music and (2) actively participating in a task requiring spatial-temporal reasoning.

If we examine the neuropsychological research on music processing, however, the basic tenets of the Trion model seem implausible. The research of Peretz and her colleagues is particularly relevant. Peretz has shown that much of music perception and cognition is relatively modular, and, moreover, that individual aspects of music cognition are relatively modularized and independent of other aspects.⁴⁴ For example, melody and rhythm are processed independently and in different parts of the brain,⁴⁵⁻⁴⁷ lyrics are processed independently of tunes,⁴⁸ and perceiving musical emotion is independent of memory for music.^{49,50} Most importantly, Peretz has studied brain-damaged patients with amusia, and none has exhibited accompanying deficits in spatial abilities. For example, one of her amusic patients could not discriminate tones that differed by gross differences in pitch, yet she continued to drive safely around Montreal. In short, there is substantial evidence for modularity of music processing and for independence of various aspects of music. Such evidence is inconsistent with the notion that cortical activity is similar across a variety of musical activities (performing, composing, and listening) and that such patterns of activation are identical during spatial-temporal reasoning.

LONG-TERM SIDE EFFECTS OF MUSIC LESSONS

Although the short-term Mozart effect appears to be independent of Mozart in particular and of music in general, it is still possible that positive, relatively long-term cognitive side effects result from taking music lessons. Indeed, the two issues may be orthogonal. To anticipate the conclusion, the relevant findings reviewed below are consistent with the idea of an association between musical training and non-musical benefits, but they fall far short of being conclusive. The studies are grouped according to design (correlational, quasiexperimental, or experimental).

Correlational Studies

Several studies have examined whether musical ability (rather than musical training) is correlated with other kinds of abilities. Positive associations imply that improving one's musical ability through formal lessons would be accompanied by

nonmusical benefits. In correlational designs, however, it is always impossible to make firm conclusions about the direction of causation when associations are discovered. It is also impossible to rule out the possibility that the association stems from a third, unidentified variable.

Gromko and Poorman⁵¹ examined children between the ages of 4 and 13 who were enrolled in a private school. Their goal was to determine whether musical aptitude is related to children's ability to use symbols. In an initial testing session, children completed the tonal subtest of Gordon's^{52,53} musical aptitude measures. During a second session, children were tested on two tasks, one that required them to match short melodies with graphic representations and another that required them to draw graphic representations of the contour of short melodies. Performance on all three measures improved with age, and each measure was significantly correlated with the other two. These findings confirm that children's musical aptitude is predictive of their ability to interpret and produce symbolic representations of music. Because each of the outcomes was associated with age, however, it is impossible to determine whether the associations would still be in evidence if differences in age were held constant (i.e., the authors did not report partial correlations).

In an examination of performance on musical and spatial tasks that required analogical reasoning, children from 6 to 12 years of age were tested on their ability to transfer a given relation between one pair of stimuli to a novel pair.⁵⁴ As the age of the children increased, performance on both tasks improved. Moreover, age-related improvements were virtually identical across tasks. As with the study by Gromko and Poorman,⁵¹ however, the association between the music and spatial tasks could be a consequence of the fact that older children performed better on both tasks.

Lamb and Gregory⁵⁵ studied the association between reading and musical abilities in a sample of 5-year-old children. Reading abilities and phonemic awareness were positively associated with pitch-discrimination abilities but not with the ability to discriminate timbres. These associations remained in evidence when differences in age and nonverbal intelligence were held constant. Virtually identical associations between reading abilities and musical abilities (with differences in age and IQ held constant) were reported for a sample of 9-year-old children.⁵⁶ Although these findings do not address the issue of causation, they provide evidence of an association between reading and musical abilities that is independent of age or general intelligence.

Douglas and Willatts⁵⁷ tested a sample of 8 year olds to examine whether literacy and musical ability are associated. Pairs of tones were presented in a pitch-discrimination task that required children to identify whether the second tone was higher, lower, or the same as the first. A rhythm-discrimination test required children to respond "same" or "different" to pairs of sequences played on a wood block. Literacy was measured with tests of reading and spelling. All measures showed significant pairwise correlations. When differences in receptive vocabulary were held constant, however, reading and spelling measures were associated with rhythm-discrimination abilities but not with pitch-discrimination abilities. Whereas these findings suggest that rhythm-discrimination abilities are better than pitch-discrimination abilities at predicting literacy, the results of Lamb and Gregory⁵⁵ imply that pitch-discrimination abilities are a better predictor than timbre-discrimination abilities.

Finally, Lynn *et al.*⁵⁸ examined the association between musical aptitude and general intelligence (Spearman's *g*) in groups of children 10 years of age. Children

were administered rhythm- and pitch-discrimination tasks as well as tests of general intelligence. Each of the music measures was positively associated with each of the measures of intelligence. These results suggest that musical aptitude is a function of general intelligence. Alternatively, musical aptitude may be a valid estimate of *g*. Although the association between musical aptitude and intelligence is provocative, it remains to be seen whether music lessons actually promote improvements in cognitive abilities.

Natural/Quasiexperiments

Other researchers have tested for the possibility of differences between naturally occurring groups (e.g., those with and without musical training) in nonmusical abilities. Again, because we can never be sure that the groups are identical on other potentially relevant dimensions (e.g., socioeconomic status and overall IQ), unequivocal determinations of causation are impossible.

A classic example of a relevant quasiexperiment is a study by Chan *et al.*⁵⁹ of female college students in Hong Kong (mean age of 20 years). The authors compared the verbal and visual memory abilities of women with no musical training to those of women who had taken six years of music lessons before the age of 12. Although the groups did not differ on the visual-memory task, the musically trained group outperformed the untrained group on the verbal-memory task. Unfortunately, despite the authors' claim that the groups were matched according to years of education (with $\alpha = 0.01$), closer inspection of the findings revealed that the musically trained group had significantly more education (with α set to a standard 0.05 value). In other words, it is impossible to determine whether the verbal advantage stemmed from music lessons rather than from additional years of education. Indeed, we would predict that better verbal skills would accompany higher levels of education.

Hassler *et al.*⁶⁰ examined verbal fluency and visual-spatial abilities in children 9 to 14 years of age. The children were classified into one of three groups: (1) musically talented and capable of composing or improvising, (2) musically talented but not capable of composing or improvising, or (3) nonmusicians. The groups did not differ on a test of spatial relations, but significant differences were found on tests of verbal fluency and visualization abilities, with the musically talented children outperforming the nonmusicians. At a follow-up test two years later, significant differences were found for each of the three outcome variables.⁶¹ Nonetheless, students in the composing/improvising group had more music lessons than did the other musically talented group, yet no differences between these groups on the outcome measures were evident. As such, this study provides equivocal support for the idea that music lessons are accompanied by advantages in nonmusical domains.

Two studies compared the nonmusical abilities of children enrolled in a Kodály music program with those of a comparison group who were not taking music lessons.^{62,63} The Kodály program is known for intensive training and for placing great emphasis on singing and on the development of sequential skills. The program also incorporates clapping, the use of hand signs, and simple musical notation. Hurwitz and his colleagues examined the sequencing and spatial skills of a group of seven year olds. Children in the Kodály group had taken music lessons for approximately seven months, with 40-minute lessons five days per week. The sequencing task in-

volved tapping mechanical keys in a regular manner or in time with a metronome after the metronome was turned off or its rate had been changed. Children were also given tests of spatial abilities, plus a Stroop-like test of interference. The Kodály group outperformed the comparison children on the Stroop test and on some of the spatial tests. In a separate examination of children who had completed 1 year of Kodály instruction, the Kodály group performed better than a comparison group on a reading test even though the two groups had performed identically a year earlier. A subsequent study of four- and five-year-olds' understanding of prenumber concepts showed a benefit of Kodály training only for five-year-old girls.⁶³ These results suggest that training in music may lead to nonmusical improvements, yet it is impossible to ascertain whether nonmusical aspects of Kodály training or preexisting differences between groups may have influenced the results.

Experimental Studies

The next group of studies had more-or-less random assignment of participants to experimental conditions. Thus, provided that comparison conditions were selected appropriately, we should be able to determine whether music lessons actually "cause" nonmusical cognitive advantages. As with most of the short-term (Mozart effect) studies, however, none of the studies in this group used comparison conditions that preclude the possibility of alternative explanations for the findings.

For example, six-year-old children who were taught music for seven months by means of the Kodály method showed improvements in mathematical and reading abilities that surpassed those of children without such training.⁶⁴ The researchers' goal was to examine possible by-products of a "test arts" (Kodály) program that was implemented in some first-grade classes but not in others. They examined two first-grade classes in each of two schools that were designated as "test arts" classrooms and another two from both schools that were "standard arts" classrooms. If we assume that the classrooms were assigned to the two arts programs at random, we can consider the design to approximate a "true" experiment. The reported advantage for the test-arts classes is remarkable when we consider that in the previous year children in the test-arts classes were actually *behind* the standard-arts children in terms of the proportion who had reached the national average grade level. Although these results are promising, children in the standard-arts classrooms did not participate in activities focusing on "sequenced skill development" as did children in the test-arts (Kodály) classrooms. Again, this confounding makes it impossible to attribute the remarkable recovery and achievements of the test-arts classrooms to training in music per se, rather than to other nonmusical aspects of the Kodály program.

In another study, four-year-old children who received individual 10-minute piano lessons once or twice a week for six to eight months performed better on a test of spatial skills than children assigned to comparison conditions.¹¹ Nonetheless, other aspects of the design question the reliability of the effect. For example, some of the children had 33% more lessons than other children, yet this additional training in music had no effect on performance. Moreover, the primary comparison condition involved playing with commercial software programs on a computer. Although a computer instructor provided one-on-one instruction about how to use the computer and open the programs, the software (not the instructor) was designed to teach the children basic skills in reading and arithmetic. As such, superior levels of perfor-

mance in the piano group could be the consequence of additional instruction from an adult nonparent.

Standley and Hughes⁶⁵ found that children in prekindergarten classes (four to five years of age) who took 15 music lessons over a period of two months showed enhanced pre-reading and writing skills compared to other children. Children in the comparison condition were exposed to the regular prekindergarten curriculum but had no additional lessons of any kind. Again, it is impossible to determine whether the observed numerical and verbal benefits arose specifically from music instruction or from pedagogical differences that were independent of musical training. The investigators noted that "it was also apparent from the children's reaction that the music activities provided pleasure and excitement about academic participation, possibly generating long range motivation for reading and writing" (p. 83). Nonmusical activities that generate similar levels of pleasure and excitement could generate similar increases in motivation.

Gromko and Poorman's⁶⁶ study of three- and four-year-old children enrolled in a private Montessori school is similar to Standley and Hughes'⁶⁵ study just described. Children in the music group were provided with weekly group music lessons in addition to the regular curriculum, but the comparison group received no additional lessons of any sort. As such, the modest gains in nonverbal IQ witnessed for the music group relative to the comparison group can be attributed simply to additional educational instruction from an adult.

Three recent experimental studies suffer from similar methodological problems. Each compared young children enrolled in music-education programs with children in "control" groups who had no comparable extraschool activities.⁶⁷⁻⁶⁹ One study provided three years of piano lessons free of charge to children in the fourth to sixth grades.⁶⁸ These "piano" children performed better than children in a control group on a comprehensive test of cognitive abilities after the first and second years, but the difference disappeared after the third year. Between-group differences during the first two years stemmed solely from differences in spatial abilities. In another study, kindergartners were provided with group keyboard lessons for eight months.⁶⁹ The keyboard children showed greater improvement than a control group on tests of spatial abilities, but there was no difference between groups on a test of recognition. A third study examined the influence of a 30-week structured music curriculum on cognitive development.⁶⁷ Treatment and control groups of six year olds were administered six subtests from the Stanford-Binet Intelligence Test before and after the curriculum. The treatment group showed relatively larger gains on a single subtest that measured capacity of short-term memory (Bead Memory).

Another recent study examined possible side effects of group keyboard lessons that were provided free of charge to children six to eight years of age.⁷⁰ A control group had computer lessons with a commercial software program designed to improve English language skills. Both groups were also given lessons intended to enhance spatial abilities by playing with a software program designed by the researchers. Unfortunately, the main outcome variable consisted of scores on a "testing" version of the same spatial software, which has unknown reliability and validity. Moreover, aggregate scores on the outcome tests did not differ between groups. The investigators reported a significant advantage for the keyboard group on a subtest of mathematical fractions and proportions, and they concluded that improved musical and spatial skills lead to improved mathematical abilities. These results

would be more convincing if they had been obtained with standardized tests and if the piano group had performed better overall or at least on subtests for which clear predictions were made a priori.

The studies just reviewed provide consistent *suggestive* evidence that music lessons have positive nonmusical side effects. Nonetheless, specifics of the reported associations vary widely from study to study. If we suspend our disbelief, however, and assume that music education affects abilities in other areas, how could we account for this influence?

A number of neurological studies describe ways in which music lessons affect cortical development. Compared to nonmusicians, accomplished players of string instruments show increased representation in the cerebral cortex for the fingers of their left hand,⁷¹ which implies that musical training can alter patterns of cortical organization. Indeed, cortical representations are especially large for those who begin music lessons at an early age when the brain is relatively plastic. Although the size of the corpus callosum is larger in musicians than in nonmusicians, this effect is particularly notable in musicians who began taking lessons before the age of 7.⁷² Relatively large brain asymmetries are also evident among musicians who have absolute (perfect) pitch,⁷³ and this relatively rare ability to name and produce pitches in isolation is evident predominantly among musicians who begin lessons in early childhood.⁷⁴ Moreover, the representation of piano tones in the auditory cortex differs in musicians than in nonmusicians,⁷⁵ although genetic factors or simple exposure to music could also play a role.⁷⁶ Finally, specific cortical areas in the right hemisphere are activated when reading a musical score but not when reading one's primary or secondary language.⁷⁷

Consequences of an enriched environment on other species (e.g., rats and mice) include denser patterns of dendritic branching and a greater number of hippocampal neurons.^{78,79} If music education represents an enrichment of a child's environment, such enrichment could promote neurological development, which could, in turn, influence abilities in other domains. Music, however, is simply one of many ways to enrich a child's environment. Moreover, music education is a complex process that involves many different dimensions. As such, it may be more fruitful to examine the effects of music education at a behavioral level instead of attempting to map such effects directly onto cortical architecture.

We know that schooling improves a wide variety of cognitive skills and that this association is not simply a by-product of maturation.^{80–83} For young children in particular, schooling is more effective in smaller classes.^{84,85} Reviews of intervention programs for children who are at risk of academic failure suggest that extended one-on-one contact with a supportive adult is a common feature of successful interventions.^{86–87} Thus, music lessons, which are typically taught individually or in small groups, may confer nonmusical benefits for children by providing close and extended contact with an adult other than a parent or teacher. If this is the case, then similar side effects should be evident with other types of lessons that provide similar levels of contact (e.g., chess, drawing).

Music lessons may be unique, however, because of their focus on a particular combination of factors, such as hours of individual practice, learning to read music, attention and concentration, timing, ear training, sight reading, constructive feedback from the instructor, and exposure to music.⁸⁸ Thus, positive transfer effects to nonmusical domains, such as language, mathematics, or spatial reasoning, could be

similarly unique for individuals who take music lessons. On the other hand, music lessons are likely to improve many *general* skills, such as attending to rapidly changing temporal information, honing skills of auditory stream segregation, developing the ability to detect temporal groups, becoming attentive to signals of closure and other gestalt cues of form, developing emotional sensitivity and expressiveness, and developing fine motor skills. These general skills should be particularly likely to transfer to a variety of nonmusical domains.

As someone who took music lessons from the age of five and practiced regularly for the next 11 years, I feel changed—probably for the better—in ways that seem specific to my involvement with music. It remains to be seen, however, whether this personal observation will withstand the test of rigorous experimental investigation.

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