

Chapter VII

UNPACKING THE IMPACT OF MUSIC ON INTELLIGENCE

James S. Catterall and Frances H. Rauscher

ABSTRACT

Reports that exposure to music causes benefits in nonmusical domains have received widespread attention in the mainstream media. Despite the fact that the term “Mozart effect” has been grossly misapplied and over-exaggerated, the effects of music on intelligence have caught the interest of scientists concerned with cognitive, neuroscientific, and educational approaches to the study of music. This chapter addresses the question, “How does music learning affect other intellectual capacities?” We review research on the effects of music instruction on spatial abilities and arithmetic, followed by an examination of its effects on other cognitive skills, including visual-motor integration and verbal/reading performance. After suggesting some possible mechanisms for these effects, we then discuss a widely-publicized paper suggesting that music instruction enhances general intelligence (IQ). We revisit the data from this study to investigate if the reported IQ gains were driven by one of the two sub-domains measured, i.e., visual-spatial reasoning or verbal reasoning. We conclude from our analyses that the gains in general intelligence derive from gains in visual-spatial reasoning skills more than from gains in verbal skills—for all children and particularly for children who scored low on the IQ test prior to musical instruction.

INTRODUCTION

This chapter extends a tradition of research on music and cognition that has buoyed the careers of psychologists, sent parents to the school board demanding support for an orchestra, and left music teachers and musicians scratching their heads over their professional and social purposes. We refer of course to the popularized notion that “music makes you smarter”

as well as to responding convictions that music is about skill, appreciation, affect, emotion, and beauty. Propelled by events catalogued below, the past fifteen years have seen cognitive specialists, neuroscientists, music educators, and an economist or two train their lenses on learning in music to see how music experience affects individuals. Of overwhelming and primary interest in this tradition are the increasingly documented influences of music on how people think. The quest plays out in behavior broadly conceived as well as the inferences we can derive from behavior about the contours of cognition. In recent years, in part because of the accelerating quality of imaging techniques, scientists have examined the manifestations of behavior and experience, including the musical, on brain function and structure.

In this chapter we try to push forward our understanding of music learning and intelligence. Very few music studies have enlisted full-blown standardized tests of intelligence, but a recently published and widely heralded report (Schellenberg, 2004) supports a broad claim that music enhances general intelligence. We revisit the impressive and detailed data from this study to investigate a question growing from a broad current in cognitive music research: Can measured gains in general intelligence be driven disproportionately by gains in a broad sub-domain of thinking capacities, namely spatial-temporal or visual-spatial thinking? We raise this question with hopes that any answers will advance our knowledge of music's impacts on cognition and how such impacts materialize.

HISTORICAL ROOTS

The study of the extra-musical benefits of music exposure has a long history in Western intellectual culture. Early Greek education emphasized rhetoric and mathematics, athleticism, the visual arts, and music. As the Greek curriculum expanded to include other subjects, there ensued a debate regarding the role of music in the educational system. The debate continues today. With the continuing cuts to school budgets, music teachers throughout the world are continually forced to justify their existence. A brief examination of the history of public education in the United States provides some insight into why music teachers have to fight for their right to teach music in the public schools.

The primary goal of education for the Puritans was the ability to read the Bible. Developing basic literacy remained the principle purpose of both private and public (government-funded) education throughout the nineteenth century. However, on August 28, 1838 the School Board of Boston Massachusetts made music a part of the regular curriculum. It was determined that music should not occupy more than two hours a week, that it should be provided at a fixed time throughout the city, and that the classroom teacher must be present during all lessons in order to maintain order. The music teacher was paid \$100/year, out of which he or she was expected to provide the piano. This marked the first time in the U.S. that music education was provided in an organized fashion with a teacher paid by public funds. But the original justification for including music in the curriculum showed no interest in artistic goals. Instead, it emphasized the broad educational goals supported by the Boston school board at that time. The development of reading, writing, and arithmetic skills remains a preemptive goal for public education. The failure of the public schools in recent years to

deve
educ

educ
valu
and
mus
base
of m

perf
disc
follo
Pos.
rece
(Sch
cog
Per
scie

199
are
mir
mo
rela
199
nev
inte
& J
fin
Fur

develop basic abilities in these skills has resulted in a school environment in which arts education is not a high priority.

MUSIC IN TODAY'S CURRICULUM

Today, music instruction is usually considered an educational add-on, and music education programs are being scaled down or eliminated. Although most music teachers value artistic goals above all, these values unfortunately are not shared where they matter, and music teachers are often expected to justify their employment by resorting to claims that music has extra-musical benefits. Although we believe it is myopic to justify music programs based on their possible non-musical benefits, we believe the study of the non-artistic effects of music instruction is an important contribution to the music cognition literature.

CHAPTER OVERVIEW

After dispelling a common myth regarding the effects of listening to music on cognitive performance, this chapter outlines some of the cognitive effects of music instruction. A discussion of the effects of music training on spatial-temporal abilities and arithmetic is followed by a brief outline of some of the other cognitive benefits of music instruction. Possible mechanisms for these effects are then considered, followed by a description of a recent study exploring the effects of music instruction on general intelligence (i.e., IQ) (Schellenberg, 2004). The remainder of this chapter focuses on "unpacking" some of the cognitive benefits described by Schellenberg (2004), with the emphasis on *Verbal IQ*, *Performance IQ*, and arithmetic skills. The chapter concludes with a discussion of the scientific and educational implications of this new research.

THE MYTH OF THE MOZART EFFECT

The announcement of the "Mozart effect," a term originally applied by the media (Knox, 1993), has recently spawned countless articles, books and recordings making assertions that are largely unsubstantiated. In the original study college students who listened to the first 10 min of Mozart Sonata K. 448 (including the first movement and a small portion of the second movement) scored higher on a spatial-temporal reasoning task than after they listened to relaxation instructions or silence (Rauscher, Shaw, & Ky, 1993; see also Rauscher & Shaw, 1998). The effect was short-lived and small. Nevertheless, the report was touted by various news media, popular magazines, and entrepreneurs as an effortless way to boost children's intelligence. The study's authors have not supported these claims (Rauscher, 2002; Rauscher & Hinton, 2006). The original research did not utilize children as subjects, and the initial finding was specific to one aspect of intelligence only (spatial-temporal reasoning). Furthermore, current research on the "Mozart effect" in adults suggests it is due to arousal,

mood, and/or preference rather than to music in general or Mozart in particular. Several studies support this hypothesis (for review, see Schellenberg, 2005), and further suggest the effect is not limited to spatial-temporal abilities (Schellenberg et al., 2007). To our knowledge, only six published studies have searched for a "Mozart effect" in children. One study found an effect (Ivanov & Geake, 2003); one study did not find an effect (McKelvie & Lowe, 2002); two studies found a musical preference effect rather than a Mozart effect (Schellenberg & Hallam, 2005; Schellenberg et al., 2007); and two studies found neither a Mozart effect nor a musical preference effect (Crncec, Wilson, & Prior, 2006; Hui, 2006). The existence of a "Mozart effect" in children is thus highly debatable and certainly not what early enthusiasts had hoped.

THE EFFECTS OF MUSIC INSTRUCTION ON SPATIAL REASONING AND ARITHMETIC

Despite the controversy surrounding the "Mozart effect," its discovery has prompted a renewed interest in the effects of music on cognition. Recently, researchers have attempted to understand the relationships between music exposure and cognition by providing children with music *instruction* and then testing their performance using a variety of cognitive tasks. Piano instruction, voice instruction, and rhythmic training have been found to improve cognitive performance. For example, Rauscher et al. (1997) assigned students from three preschools to music, computer, or no instruction groups. The instruction groups received several months of individual instruction in either piano keyboard coupled with group singing lessons or computer usage. The children were tested using one spatial-temporal reasoning task and three spatial recognition tasks taken from the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R) (Wechsler, 1989) before and after instruction began. Results indicated that children in the music group scored higher on the spatial-temporal task only. There were no differences in the children's pre- and post-test scores on the spatial recognition tasks. The computer and no instruction groups did not improve significantly on any of the tests administered. This study should be interpreted with caution, however, because only one of the three preschools permitted random assignment to groups.

A study with older (9-year-old) children yielded similar effects, although the enhancements did not persist into the third year of the three-year study (Costa-Giomi, 1999). One group of children received weekly piano lessons whereas another group received no lessons. All children were pre- and post-tested using verbal, quantitative, and spatial subtests. An overall score of intelligence was derived from the subtest scores. The children in the music group's overall intelligence scores were higher after the second year of the study. They also scored higher on the spatial subtest after both the first and second years of the study, but there were no differences between the groups on the overall intelligence measure or on any subtest, including the spatial subtest, by the end of the third and final year. This study is somewhat consistent with research finding that the spatial-temporal scores of children who received keyboard lessons in second grade (at approximately age 7) did not differ from children who received no lessons, whereas children enrolled in the same school who received lessons starting in kindergarten (age 5) or first grade (age 6) did significantly differ from

cont
grou
orde

skill
2004
addi
the
rese
(KA
Han
Ana
thos
Mat
imp
is u

to s
skil
chil
con
usin
(DI
Rev
spa
adr
ind
an
no
per
ten
AE

det
on
an
em
co;
ke
les
ad

controls (Rauscher, 2002; Rauscher & Zupan, 2000). No differences were found between any groups on a visual memory test. It is therefore possible that early instruction is necessary in order for musical learning to transfer to spatial-temporal performance.

Keyboard instruction has also been found to improve the spatial-temporal and arithmetic skills of kindergarten children in an experiment conducted with Greek children (Zafranas, 2004). Sixty-one children received two thirty-min keyboard lessons for seven months. In addition to examining the effect of the lessons on spatial-temporal abilities, a major goal of the study was to determine if effects could also be found for other tasks. Accordingly, the researcher administered six subtests of the Kaufman Assessment Battery for Children (KABC) (Kaufman & Kaufman, 1983) before and after the instruction. The subtests included Hand Movements, Gestalt Closure, Triangles, Spatial Memory, Arithmetic, and Matrix Analogies. Comparisons were made between the children's pre- and post-test scores and those of age-standardized norms. Children showed significant improvement on all but the Matrix Analogies subtest, described as an "analogic thinking task" (p. 203), with the greatest improvement found for the Hand Movements task. Although these findings are intriguing, it is unfortunate that the author did not include any tasks that do not have spatial attributes.

Three studies conducted over a period of five years also utilized the K-ABC, in addition to several other cognitive tests, to explore the impact of music instruction on a variety of skills (Rauscher, LeMieux, & Hinton, 2005). For the first study, Head Start⁴ preschool children were randomly assigned to one of three conditions: Keyboard instruction (n=33), computer instruction (n=28), or no instruction (n=26). The children were pre- and post-tested using the KABC (Kaufman & Kaufman, 1983), the Developmental Test of Visual Perception (DTVP-2) (Hammill, Pearson, & Voress, 1993), the Test of Auditory Perceptual Skills-Revised (TAPS-R) (Gardner, 1996), and the WPPSI-R (Wechsler, 1989). These tests measure spatial-temporal, visual-spatial, auditory, verbal, and arithmetic skills. Overall, the authors administered twenty-six subtests. The children in the keyboard group received 48 weeks of individual weekly lessons distributed over two academic years. The computer group received an equal number of individual lessons on a laptop computer. The no-lessons group received no individualized instruction. Results indicated that the children in the keyboard group performed higher than the computer or no lessons groups on the tasks containing spatial or temporal content and arithmetic, but not higher on the Matrix Analogies subtest of the K-ABC (replicating Zafranas, 2004) or any of the verbal measures.

The second of the three studies (Rauscher, LeMieux, & Hinton, 2005) was designed to determine if the type of music instruction children received had measurably different effects on cognition. Most researchers agree that musical skill is an alliance of a number of separate and relatively independent abilities. The authors proposed that early music instruction emphasizing different musical skills would produce correspondingly differential effects on cognitive performance. Head Start preschoolers were randomly assigned to four groups: keyboard instruction (n=34), singing instruction (n=28), rhythm instruction (n=35), or no lessons (n=26). Lessons were again provided for 48 weeks over two years. The same subtests administered in the first study were given before and after instruction. The researchers

⁴ Head Start is a federally-funded enrichment program designed to help underprivileged preschool children begin primary school on an equal academic footing as their middle-income peers.

predicted improvement in spatial-temporal tasks following all types of music instruction, greater improvement in mental imagery tasks following singing instruction (due to singing's strong reliance on auditory imagery), and greater improvement in temporal tasks following rhythm instruction (due to rhythm training's emphasis on the temporal qualities of music). As in the first study, the children in the three music groups scored higher than the control group on the spatial, temporal, and arithmetic tests. As predicted, the rhythm group scored significantly higher than the keyboard, singing, or control groups on the temporal and arithmetic tests. Scores on the verbal tests did not differ from controls. The prediction regarding the effects of singing instruction on mental imagery tasks was not supported.

The third of the three studies (Rauscher, LeMieux, & Hinton, 2005) was conducted to test the durability of the enhancements found in the first two studies, as well as to compare the scores of the Head Start children who participated in Studies 1 and 2 (now in second grade and kindergarten) to those of randomly chosen age-matched middle-income children and disadvantaged children who were not enrolled in a Head Start program. The researchers thus compared the scores of the children who received music lessons in Studies 1 and 2 to three groups of age-matched children: (1) Head Start children who did not receive music instruction; (2) at-risk children who were not enrolled in Head Start, and (3) middle-income children. The children who participated in the control ($n = 24$) and piano ($n = 31$) groups in Study 1 were re-tested, as were children from the music groups who participated in Study 2 (piano, $n = 27$; singing, $n = 20$; rhythm, $n = 29$, following attrition). Twenty-seven at-risk kindergartners, 24 at-risk second-graders, 32 middle-income kindergartners, and 28 middle-income second graders were also tested. All children were administered the K-ABC Hand Movements, Number Recall, Gestalt Closure, Faces and Places, Arithmetic, and Riddles subtests. Although interviews revealed no differences in the extent of music instruction between the three disadvantaged groups, 12% of children in the middle-income group received individual instrumental instruction outside of school. Results indicated that the Study 1 music groups' scores on tasks previously enhanced by the instruction (Hand Movements, Gestalt Closure, and Arithmetic) remained higher than age-matched at-risk children who were not in Head Start and Head Start children who did not receive keyboard instruction. The Study 1 music groups' scores did not differ from those of the middle-income group on any test. All music groups from Study 2 scored significantly higher than age-matched at-risk and Head Start groups on the Arithmetic, Hand Movements, Number Recall, and Gestalt Closure tasks. However, the arithmetic scores of the children who received rhythm instruction in Study 2 were significantly higher than age-matched middle-income children. It is important to note that the children from Study 1 were tested two years after instruction was terminated, suggesting that the effects of music instruction on spatial abilities may persist.

Another study provides additional support for the notion that music instruction enhances young children's spatial-temporal task performance (Gromko & Poorman, 1998). Seventeen preschool children received seven months of weekly music lessons consisting of songball instruction along with singing, rhythm, and kinesthetic activities. The children were encouraged to practice at home between lessons. Seventeen children received no instrumental instruction. The performance subtest of the WPPSI (consisting of five tasks) was administered at the beginning and end of the seven-month period. The children's scores on

the five tasks were used to compute their “*Performance IQ*” The pre-test *Performance IQ* scores were then subtracted from the post-test *Performance IQ* scores to yield gain scores. The researchers reported that the gain in *Performance IQ* of the music group was greater than the gain in *Performance IQ* of the control group, and concluded that “...we believe music training can have a positive effect on the development of spatial intelligence in preschool children” (p. 180).

The Stanford-Binet Intelligence Scale (Thorndike, Hagen, & Sattler, 1986) also has been used to test the generalizability of the effects of music instruction (Bilhartz, Bruhn, & Olson, 2000). Six of the eight subtests were administered to four- to six-year-old children: Vocabulary, Memory for Sentences, Bead Memory, Pattern Analysis, Quantitative, and Copying⁵. Thirty-six children participated in a Kindermusik program that included vocal exploration, pitch matching, learning to read music, and instruction in percussion instruments and glockenspiel. The 75-min weekly lessons were provided for 30 weeks. Thirty-five children served as the control group. Gain scores were calculated by subtracting the children’s age-standardized scores on the pre-test from their scores on the post-test. The authors found no differences in gain scores between the music and control groups on any measures other than Bead Memory, an abstract reasoning subtest. Furthermore, only those children who met the minimum compliance criteria for the music instruction (e.g., completed take-home assignments, had parental assistance, and attended classes regularly) showed the improvement, with the degree of improvement increasing linearly with the amount of music instruction. The authors suggest that the Bead Memory subtest “measures both visual imagery and sequencing strategies” (p. 629) and concluded that “the results of this study lend support to the hypothesis that there is a significant link between early music instruction and cognitive growth in specific nonmusic abilities” (p. 629).

A study conducted in four lower-income Milwaukee public schools found improved spatial-temporal and arithmetic scores for children who received classroom keyboard instruction (Rauscher, 2005). Kindergarten through 5th-grade children (n=627) were assigned to one of two conditions: keyboard or no lessons. All children were tested at the beginning and end of each of three years using three verbal tests, two mathematics tests, and one spatial-temporal test. There were several problems with the instruction during the first year of the study. Music teachers appointed by the school district did not receive classroom assignments until one month into the school year. They were unfamiliar with the keyboard curriculum and had not taught piano in the classroom before. In addition, there were high rates of absenteeism, lateness, and conduct disorders among the children, and classroom space was inadequate. These problems persisted through the second year of the study. During the third year, a music specialist with proficiency teaching keyboard to elementary school children at a different school district volunteered to assist the teachers in the classroom and share her expertise, greatly improving the quality of the instruction. No significant differences were found between groups for the cognitive measures during the first two years of the study. Differences between the piano and control groups emerged for the arithmetic and spatial-temporal tests during the third year of the study only, after the keyboard instruction had improved. These effects were found only for the kindergarten and first grade children. There

⁵ The Copying subtest was later eliminated from the analysis due to poor inter-scoring reliability.

were no differences between any groups on the verbal measures. This research emphasizes the importance of quality music instruction for cognitive transfer effects, and supports previous research reporting differential effects of piano instruction on cognition.

Differences in the visual-spatial skills of adult musicians compared to non-musicians have been found using a reaction time task (Brochard, Dufour, & Després, 2004). To test their vertical discrimination, subjects were presented with a small target dot either above or below a horizontal reference line. Horizontal discrimination was tested by presenting the dot either to the left or to the right of a vertical reference line. Two experimental conditions were employed. In one condition ("line on"), the reference line was present during the presentation of the dot. In the other condition ("line off"), the reference line was absent. The subjects' task was to indicate which side of the reference line the dot was flashed. The researchers predicted that "...if musical expertise has a long-term influence on visual-spatial abilities, ...musicians' performance on both perceptual "line on" and imagery "line off" conditions [would] be significantly better than non-musicians'. Moreover, if this effect relies on a more efficient use of visual representations, an advantage of musical expertise should be greater in the imaging ("line off") conditions" (p. 104). The data supported these predictions. The authors concluded that "such perceptual and imagery advantages partly explain why music instruction generally increases children's scoring in visuospatial tasks (such as paper folding, mental rotation, and tridimensional reasoning) which all involve the mental manipulation of visual representations on several dimensions" (p. 106).

An additional study compared four classrooms of first-grade children who received seven months of Kodály music instruction along with visual arts training (experimental group) with four classrooms of children who received the school's standard arts curriculum (control group) (Gardiner et al., 1996). Although more students in the experimental group scored below grade averages for reading and math than the standard curriculum children in kindergarten, after the special arts training in first grade they scored equal to the standard group in reading and above them in math. When tested again in the second grade, following an additional 7 months of special arts training, the experimental group's scores again equaled those of the control group in reading and exceeded their scores in math. Unfortunately, because the music and arts instruction were provided together it is not possible to determine if the results were due to the music curriculum.

Graziano, Peterson, and Shaw (1999) explored the effects of keyboard instruction coupled with a video game designed to train spatial-temporal skills and proportional math concepts. There were 6 groups in the study, three of which are discussed here. One group received the keyboard lessons together with the video game, a second group interacted with the video game and received lessons in English, and a third group received no special training. Children were pre-and post-tested with three spatial subtests of the Wechsler Intelligence Scale for Children (WISC-III) (Wechsler, 1991), and were also post-tested with the Spatial-Temporal Math Video Game Evaluation Program, a software program designed by the study's authors to assess the children's proportional math reasoning. Results indicated that the keyboard/video game group scored significantly higher on the proportional reasoning test than the English/video game group. Both groups scored significantly higher than the no lessons group. The scores of the children in the two video game groups did not differ from each other on the WISC-III subtests, although both groups scored higher than the no lessons

group on these measures as well. This study suggests a link between music, spatial reasoning, and the spatial aspects of mathematics.

Two meta-analytic studies are relevant to the above discussion on the effects of music instruction on spatial and mathematical abilities. Hetland (2000) performed three meta-analyses on fifteen published and unpublished studies examining the relationship between music and non-musical outcomes. The age of the subjects ranged from 3 to 15 years, and the duration of the music instruction ranged from four weeks to two years. The goal of Hetland's first analysis was to test the hypothesis that music instruction improves spatial-temporal reasoning. Her second analysis sought to examine the effects of music instruction on general intelligence as measured by Raven's Standard Progressive Matrices (Raven, 1986), and the third analysis included studies that used spatial tests other than spatial-temporal reasoning tests. From her first analysis, Hetland concluded that "active music instruction lasting two years or less leads to dramatic improvements on spatial-temporal measures" (p. 203). The second analysis revealed a small but insignificant relationship between music instruction and subjects' scores on Raven's Standard Progressive Matrices test, and the third analysis suggested that the effects of music instruction are not limited to spatial-temporal tasks only, but rather other spatial tasks may be affected as well. However, the small number of studies used in the third analysis makes these results difficult to interpret.

A second meta-analytic study explored the effects of music instruction on mathematical abilities (Vaughn, 2000). Twenty-five studies were included and assigned to one of three groups: correlational, experimental-music instruction, and experimental-music listening. Separate meta-analyses were performed on each group. The analysis performed on the first group of studies yielded a modest relationship between music instruction and mathematics achievement. However, the researcher points out that, "...while correlation is a necessary condition for causality, it is not sufficient" (p. 154). One cannot conclude from this analysis that music instruction *caused* higher math achievement. The analysis of the experimental-music instruction studies showed that music instruction provided to children does indeed appear to cause increases in mathematics achievement. Finally, the author concluded from her third analysis on the music listening studies that "playing music in the background while students are taking math tests has only a small, positive effect at best" (p. 163).

In addition to the experimental and quasi-experimental research, a number of correlational studies have also explored the link between music and spatial intelligence. It is important to note here that correlational studies differ from experimental and quasi-experimental studies in that causality cannot be established due to lack of manipulation of independent variables. However, correlational studies can help determine the relationship between variables. In general, it appears that spatial and musical skills are related (Hassler & Birbaumer, 1988; Hassler, Birbaumer, & Feil, 1985; Hassler, Birbaumer, & Feil, 1987; Hassler & Feil, 1986; Hassler, Nieschlag, & de la Motte, 1990; Karma, 1982; Orsmond & Miller, 1995).

THE EFFECTS OF MUSIC INSTRUCTION ON OTHER COGNITIVE ABILITIES

Although the data supporting the effects of music instruction on spatial abilities is compelling, a series of other studies supports the notion that music training may enhance other skills as well. In particular, music instruction has been found to enhance visual-motor integration. A study examining the effects of Kodály training on first-grade children found that children who received the training scored higher on a visual-motor integration task than children who did not receive the lessons (Hurwitz et al., 1975). The task required the children to copy complex figures, some portraying three-dimensional spatial relationships. Other spatial tasks were also administered, but the effects appeared to be found only for the boys.

Orsmond and Miller (1999) assessed three- to six-year-old children using one verbal task measuring receptive vocabulary, a melody recognition task, and three types of spatial tasks, including a visual-motor integration task. Twenty-nine children were enrolled in Suzuki music programs and 29 children received no music lessons. The researchers predicted improvement for the music group on the melody task and the three spatial tasks following four months of music instruction. No improvement was predicted for the verbal task. Results indicated that the children in the music group improved significantly on the melody recognition and visual-motor integration tasks. Little improvement was found for the other spatial tasks. Receptive vocabulary was not affected by the music training. The authors concluded that "music instruction improves fine motor skill" (p. 35).

A provocative study by Lamb and Gregory (1993) suggests that the aural skills involved in learning music can affect phonemic awareness, an important skill in learning to read. The authors tested 18 five-year-old children using a variety of reading, phonemic, and musical tasks. A test of general nonverbal ability, the *Coloured Progressive Matrices* test (Raven, 1956) was administered as well. The musical test was designed by the authors, and included measures of pitch and timbre discrimination. Results indicated that pitch discrimination was significantly correlated with both phonemic awareness and reading scores, which also were correlated with each other. Timbre discrimination and the matrices test did not correlate with any measures. Although this was a correlational study and precludes causal inferences, the data suggest that musical awareness may be a reliable predictor of phonemic awareness and reading ability.

Music training has also been found to affect verbal memory (Chan, Ho, & Cheung, 1998; Ho, Cheung, & Chan, 2003). In one study, the researchers compared the verbal and visual memory scores of children ages 6 to 15 who had received 0 to 5 years of music instruction (Ho et al., 2003). Based on lesion studies showing that verbal memory is processed by the left temporal lobe and that visual memory is processed by the right temporal lobe, the authors hypothesized that music training would influence only verbal memory due to the assumption that musicians' "...left but not right temporal lobe is...better developed" (p. 439). The musically trained children were compared to a group of demographically-matched children who had received no instruction in music. The verbal memory test required the children to recall as many previously spoken words as possible following a 10- or 30-min delay period. The visual memory test was similar to the verbal memory test, only the items to be recalled were designs rather than words. The results were as predicted: The children who had received

music training scored higher than those who had not on the verbal memory test during both delay periods. There was no difference between the two groups on the visual memory test. There was also a significant positive correlation between the duration of music training and the children's scores on the verbal memory test, but not on the visual memory test. This study is consistent with research by Kilgour, Jakobson, and Cuddy (2000), which found that Canadian children with music instruction could recall more verbal material than children who had not received music instruction. It is also consistent with studies that found no differences between music and control groups on a test of pictorial memory (Rauscher, 2002; Rauscher & Zupan, 2000).

NEUROSCIENTIFIC EXPLANATIONS

The relationship of music exposure to spatial-temporal abilities is strengthened by the few studies employing neurophysiological measures. For example, an electroencephalographic (EEG) study found gamma band phase synchronization was significantly increased between the frontal cortex and the right parietal cortex during mental rotation tasks, with musicians showing greater synchronization than non-musicians (Bhattacharya et al., 2001). These findings suggest a link between music instruction and mental rotation.

A further EEG study suggests a link between music exposure and spatial-temporal reasoning. Subjects performed a spatial-temporal task immediately after listening to either a composition by Mozart or a spoken story (Sarnthein et al., 1997). The researchers found increased temporo-parietal coherence and prefrontal amplitude both during performance of the spatial-temporal task and while they were listening to the music. The parietal cortex has been implicated in the performance of a number of spatial tasks, including mirror-reading tasks (Dong et al., 2000) and visuomotor behaviors (Jeannerod, Decety, & Michel, 1994). Prefrontal cortex has been associated with working memory and with the temporal sequencing of patterns (Fuster, 1995).

EEG studies have consistently shown that oscillations in the gamma band frequency play an important role in music perception (Bhattacharya & Petsche, 2001). A recent study found that subjects who listened to music displayed increased activity in the gamma band while performing a spatial task than subjects who performed the task in silence (Jausovec & Habe, 2004). The authors concluded that listening to the music influenced visual as well as auditory brain activity. A further study by the same authors found similar results (Jausovec & Habe, 2005). The authors concluded that "...listening to a certain type of music...increases the activity of specific brain areas and in that way facilitates the selection and 'binding' together of pertinent aspects of sensory stimulus into a perceived whole" (p. 215).

A mathematical neural model of higher brain function, developed by Gordon Shaw and Xiaodan Leng, takes a slightly different approach to understanding the relationship between music exposure and spatial reasoning (Leng & Shaw, 1991). The theory is based upon Vernon Mountcastle's (1978) theory of cortical columnar organization. Mountcastle proposed that the cortex is composed of blocks of cells (about 300-500 micrometers in diameter), called columns. Adjacent blocks have very different properties of place (i.e., location in the

animal's body which, when stimulated, evokes a response in the cortical tissue) and modality (i.e., the nature of the stimuli that evoke a response and the rate of adaptation to the stimuli). The vertical groupings of neurons with similar properties were called "minicolumns." Mountcastle proposed that these minicolumns are the irreducible basic functioning units of the neocortex. They are the primary processing and distributing units in the brain, and are able to both give and receive information. He hypothesized that each column connects with 10-30 other columns in various areas of the brain, suggesting that the brain functions as a distributed system. This was a very different view compared to previous thought, which depicted brain function as varying by location. It is now generally accepted that the entire cortex is composed of a repetitive and pervasive internal structure.

Leng and Shaw (1991) created a mathematical realization of Mountcastle's theory to try to understand how the brain processes information. They combined Mountcastle's (1978) theory with William Little's (1974) analogy of neural networking and physical spin models. Their goal was to test Mountcastle's theory using various computer simulations. Leng and Shaw named their model the "trion model," with the word "trion" referring to the minicolumns, which they postulated to have three possible levels of firing activity (high, average, low). Leng and Shaw proposed that the columns can be excited into complex spatial-temporal firing patterns. (In this case, the spatial scales are the minicolumns, columns, and cortex as a whole, and the temporal scales are the various timescales that exist in the brain, such as the circadian rhythm, which operates on a 24-hour cycle). Leng and Shaw suggested that the brain has the ability to recognize these trion firing patterns when they repeat, and can also recognize symmetries among these patterns. These patterns can be learned and strengthened based on Hebb learning principles. Thus, the highly structured and organized cortex is constantly searching for patterns and symmetry in the environment, including music.

Leng and Shaw (1991) argued that the trion model explains the coding of musical structure in humans, suggesting that we are biologically wired to create and understand music—particularly music that is high in "periodicity" (i.e., the change in relative amplitude of a piece of music over time) and/or symmetry (i.e., repeating notes, intervals, durations, reversed notes, and sequences). The finding that listening to a brief passage by Mozart can temporarily improve spatial-temporal reasoning in college students—the phenomenon popularly known as the "Mozart effect" — has been cited to support this theory (e.g., Rauscher, Shaw, & Ky, 1993).

In an attempt to define and measure characteristics of periodicity and symmetry in music by different composers, Hughes (2001) analyzed over 600 compositions, representing five composers. His results indicated the highest periodicity index scores for Mozart, J.S. Bach, and J.C. Bach, all of whom are known to have produced music with highly organized musical architecture. Mozart's music also displayed greater symmetry than did the other composer's compositions. Hughes concluded that "it is likely that the superorganization of the cerebral cortex resonates with [the] great organization found in Mozart['s] music." He suggested that Mozart's music may enhance certain abilities (e.g., spatial-temporal abilities) through Hebb learning principles.

It is unfortunate that the studies examining brain function relevant to music exposure and spatial task performance all involved listening to music rather than making music. To our

knowledge, there exist no studies that have imaged people while actually performing a musical instrument, probably due to methodological difficulties involving movement artifact. However, given that playing a musical instrument typically involves listening we suggest that the brain areas involved in listening to music are also activated while making music. Given the decades of research showing that early experiences can functionally and structurally affect the developing brain (e.g., Hebb, 1949), it seems possible that early music exposure may affect related brain areas relevant to spatial task performance. It seems that among the music-related brain functions neuroscientists have imaged, spatial reasoning and understanding hold an important place.

COGNITIVE EXPLANATIONS

Given the variety of stimuli music can present and the wide range of behaviors and capacities researchers have investigated, it is no surprise that the field has not gravitated toward unifying theories. We suggest that perhaps the strongest theoretical strain running through research on music learning is a cluster of effects centering on music's reported effects on spatial reasoning and arithmetic. Similarities between music, mathematics, and spatial reasoning have been suggested for decades (e.g., Cranberg & Albert, 1988). The argument in support of such theory derives from common and vital attributes of both music and spatial ability. Perhaps the strongest of such attributes is proportional reasoning. For example, the part-whole concept is a very important construct for many spatial and mathematical problems. This concept requires understanding the relationship between parts to wholes, such as when learning percents, decimals, and fractions. In music, proportions play out in musical notes, tempo, and pitch and involve both visual and auditory perception. The understanding of rhythmic patterns, in particular, seems reliant on the part-whole concept. To process rhythm, for example, the musician must repeatedly mentally subdivide the pulse in such a way that whole notes can be conceptualized as two half notes, four quarter notes, eight eighth notes, etc., or vice versa. The task is essentially the same as other part-whole problems posed spatially or mathematically. Similar computations are required for conceptualizing intervallic pitch relationships in music. Certain musical instruments, especially the keyboard and also the string instruments, are physically configured to reinforce the importance of proportion for effective musical production and performance.

Transfer is defined as the ability to extend what has been learned in one context to new contexts (e.g., Byrnes, 1996). The notion of transfer of learning from one domain to another has proved to be extremely controversial and difficult to demonstrate (Perkins & Salomon, 1989). Researchers interested in transfer were initially guided by theories that emphasized the similarities between the initial learning experience and later learning. Thorndike (1913) proposed that the amount of transfer that could occur between two domains was dependent upon the similarity of the elements of the domains. The more equivalent the elements of the two domains, the greater the likelihood of positive transfer. To our knowledge, only one study has specifically examined the transfer between mathematical skill and musical abilities (Bahr & Christensen, 2000). The researchers examined the mathematical skills of students using tasks that were deemed to be either structurally or not structurally related to music.

Structural learning analysis (Scandura, 1984) was performed to determine the degree of overlap between mathematical tasks and musicianship. (In this study, musicianship was defined as requiring formal training in music.) This form of analysis proposes that both mathematics and musicianship require the abstraction of patterned relationships over time. Music notation was likened to the use of graphs in mathematics, with the y-axis in music representing the frequency of a pitch and the x-axis representing time. "This symbolic and pattern comprehension facility is central to all tasks of literate musicianship, and is a common 'rule' for mathematical problem solving. It would seem then that structural analysis would confirm the likelihood that music and maths may 'overlap' for symbol and pattern usage" (Bahr & Christensen, 2000, pp. 192-193).

The procedure used to test this hypothesis was quite straightforward. Eighty-five students were given a test of musicianship designed to assess their knowledge of pitch and tonality notation, keys and scales, intervals and harmony, time and rhythm, and terminology. The students were also administered a mathematics test assessing a variety of different mathematical concepts including number handling, algebraic equations, three-dimensional shape visualization, rotation, graphing, etc. Items that required pattern analysis and symbol usage were deemed structurally similar to the domain of knowledge utilized by musicians. Results indicated that the students who had formal training in music performed better on the numerical tasks identified as overlapping with musicianship skills than the students who did not have formal music instruction. The groups' scores on tasks that did not overlap were not significantly different.

Although this study is intriguing, it leaves much to the imagination of the reader as the authors did not specifically identify which mathematical tasks were identified as overlapping with musicianship, other than to say they involved pattern analysis and symbol usage. They also did not discuss the nature or duration of the subjects' musical training. It appears that the presence of musical training was inferred from the students' scores on the musicality test. It is also important to note that the students enrolled in the study were chosen based on their proficiency in mathematics. All students were recruited from math classes that catered to students who excel in mathematics. It is therefore impossible to determine in which direction the transfer occurred. Perhaps rather than musical knowledge having transferred to mathematical knowledge, mathematical knowledge transferred to musical knowledge.

We believe that the diverse tasks involved in playing a musical instrument strengthen a number of cognitive skills, including auditory, visual, and motor abilities. Measuring the overlap between the original domain of learning and the novel one requires a theory of how knowledge is represented and conceptually mapped across the domains. Transfer is thus difficult to test experimentally until the task components are identified. Although the transfer of musical knowledge to spatial-temporal or mathematical understanding may appear obvious to the musician, there is little research that has directly pursued these mechanisms. Furthermore, several other aspects of intelligence may be affected by music instruction. The latter portion of this chapter will examine this possibility.

UNPACKING THE IMPACT OF MUSIC ON INTELLIGENCE

Theory and evidence about the effects of music on spatial-temporal reasoning offer researchers a good framework for exploring diverse outcomes of music learning and experience. As illustrated above, many effects of music learning show well-reasoned and close connections to spatial relations. A strong and well-documented evidentiary base suggests learning and playing music on a keyboard can touch a multitude of spatial relationships measured by an assortment of instruments. We argued above that the configuration of the keyboard, along with the nature of written music, present logical suggestions for why such experiences engage spatial-temporal reasoning. Most researchers and musicians would agree that music is a rich symbol system indicating myriad qualities of tone, representations of distances in space, and organization around time.

Despite emphasis in music research on transfer to spatial-temporal reasoning skills, and in some cases on transfer to specific skills such as mathematics or verbal understanding, it is reasonable to wonder whether or not the main effect of music learning and experience on cognition is largely an effect on general performance capacity, or general intelligence. It is conceivable that general intelligence gains are responsible for performance gains in widely differing areas researchers have tested. We discussed above the ways that research has shown transfer of abilities from music experiences to a spectrum of capacities: literacy, general intelligence, verbal memory, spatial ability, reading ability, selective attention, and mathematics achievement⁶. As Schellenberg (2004) summed things up, "...the most parsimonious explanation of these diffuse associations is in that they stem from a common component, such as general intelligence"⁷. About three years ago, Schellenberg then set out to test the impact of music learning on general intelligence in a high-power and rigorous experimental design. As we describe this seminal research, it is clear that the study maintained classical conditions of learning experiments, the treatments were of high quality and long duration, and the reasoning system for drawing conclusions was sophisticated. In short, it is one of the most well designed studies of music and cognition we have seen. But the study left open a question vital to our purposes here: Just what does music contribute to intelligence, and how? Based on years of research, and especially its concentration on spatial reasoning skills, we wondered if any demonstrated effect of music on intelligence might not manifest disproportionately through gains in visual-spatial skills (essentially half of the leading intelligence test batteries) as opposed to gains in verbal skills (essentially the other half). As it turned out, data from Schellenberg's (2004) experiment could support an examination of this question.

⁶ Cites from Schellenberg, 2004, p. 1.

⁷ Schellenberg, 2004, p. 511.

THE SCHELLENBERG DATA: REVIEWING CONTRIBUTIONS TO INTELLIGENCE

What follows is a description of the essential components of Schellenberg's (2004) study. (Additional description and detail are available in the published work.) The experiment used random assignment of six-year-olds ($N=144$) into four groups: two music lesson groups (keyboard or voice) and two no-music groups (drama lessons or no lessons of any sort). Music and drama lessons were taught over a period of 36 weeks by high-level certified teachers employed at the Royal Conservatory of Music in Toronto, Canada. Children received their instruction in classes of six. An IQ test, the WISC-III (Wechsler, 1991) was administered before and after the 36-week period.

Compared to children in the drama and no-lesson control groups combined, the keyboard and voice groups showed greater increases in *Full Scale IQ*. The differences in effects favoring the music groups were small but statistically significant. The effect was greatest for the voice group. For this main effect assessment, Schellenberg argued that combining the music groups made sense because the keyboard and voice groups experienced similar IQ score gains, and collapsing groups was also desirable because the increased group size would make for more powerful statistical tests. Schellenberg probed some differences across groups in individual WISC-III subtests, such as verbal comprehension and perceptual organization, and found that a significant advantage showed for the consolidated music group on 10 of 12 scales.

Schellenberg's main findings are displayed in Table 1. This table shows the pre- and post- IQ scores for each of the four groups.

Table 1. Schellenberg 2004 Results
Comparisons of WISC III Full Scale IQ Score Gains:
Keyboard, Voice, Drama, and No Lessons Groups

	Group	N	Pre-Score	Post-score	Gain-score	Sig. $p < _ _ *$	Pct. Gain	Effect Size
Music	Keyboard	30	102.6 8.8	108.7 12.5	6.1	0.000	5.9%	0.44
	Voice	32	103.8 10.9	111.4 12.6	7.6	0.000	7.3%	0.55
No-Music	Drama	34	102.6 13.6	107.7 10.19	5.1	0.000	5.0%	0.37
	No Lessons	36	99.40 13.8	103.3 9.9	3.9	0.005	3.9%	0.28

* t-tests for sig. of pre- to post-score gains;

Effect size = gain score / std. deviation of No Lessons group; simple standardized gain for No Lessons group. Difference in gain scores across groups is reliable ($p=.05$);

Gain scores of music groups are similar ($p<.08$);

Gain scores of No-Music groups are similar ($p<.07$).

The advantage for the music groups (keyboard and voice) appears here as greater average gains in IQ scores. The voice group outpaced the keyboard group; the no-lessons group

showed the smallest gain. That all groups gained to some degree is not surprising since the general pattern of WISC-III IQ scores shows increases over time for six-year-olds. That the effect of the drama group fell short of that of the music groups addresses an important concern in this and many studies. As pointed out above, it is possible that more general qualities of the disciplined study of music might characterize disciplined specialized study in other domains, for example, or that a productive arousal of interest in music lesson groups might be no different than arousal witnessed in drama education. This study's data suggest that something small but significant transfers from music – more than from drama. The most aggregated expression of the implication of this study appears in its published title: *Music Lessons Enhance IQ* (Schellenberg, 2004).

CAN THIS STUDY TELL US MORE?

Long before the publication of Schellenberg's work, the "music raises IQ" results of his study were transmitted widely in the popular media. This dissemination bore a rough similarity to the phrase "Mozart makes you smarter" that was popularly celebrated more than a decade earlier. The latter ushered in a period of active studies of transfer from music and artistic learning, many discussed above. This field has been propelled in recent years by the interests of cognitive neuroscientists exploring the impacts of music on brain function.

Cognitive researchers who focused on music, including ourselves, naturally took an interest in the news of Schellenberg's study. Schellenberg graciously furnished both of us with a proof of his upcoming publication. After considering the study, several questions not addressed in the article stood out to us on the basis of prior research in music and learning. The most important of these was the potential in the data for investigating the possibility that spatial reasoning gains for the music subjects may have disproportionately accounted for the reported gains in general intelligence. While the study concluded that keyboard and voice lessons affect intellectual capacity generally, prevailing theory in music learning and transfer suggest that developments in spatial-temporal reasoning ability stand out among measured effects of music on cognitive function. A more fine-tuned curiosity pointed to the keyboard group in this study. Based on what research has reported to date, there is good reason to believe that music learning involving the keyboard might advance spatial abilities more than would learning in other types of music or on other musical instruments. The data from Schellenberg's study seemed to offer ways to sort these things out.

UNPACKING THE IMPACT OF MUSIC ON INTELLIGENCE

We conducted an independent analysis of Schellenberg's data to explore the possibility that differential gains within the construct of general intelligence accounted for the *Full Scale IQ* results. More specifically, we theorized that music students in the study might have experienced larger gains in the underlying WISC-III intelligence scales related to spatial ability than in other scales. Our procedure was to revisit Schellenberg's WISC-III results to see if the embedded scales could tell us more about the cognitive development of the subjects

during the course of the experiment. Results on a wide range of measures were available to us. The WISC-III derives its *Full Scale IQ* measure by combining a six-item *Verbal IQ Scale* and a five-item *Performance IQ Scale*. The verbal scale contains measures of these items: *Information* (general "trivia-like" questions), *Comprehension* (common sense reasoning, judgment), *Vocabulary* (knowledge of words and grouping words by meaning), *Similarities* (categorizing information, abstract reasoning), and *Arithmetic* (attention, concentration, and numerical reasoning (oral)). The *Performance IQ Scale* contains measures of these items: *Object Assembly* (visual analysis), *Block Design* (spatial problem solving with puzzles), *Picture Arrangement* (sequential, logical thinking), *Picture Completion* (identifying missing parts of pictures; mastery of essential detail), *Symbol Search* (locating symbols in a grid of symbols; rate of processing new information), and *Coding* (visual-motor skills; marking rows of shapes with appropriate codes).

SPATIAL REASONING IN THE WISC-III

There is ample precedent for enlisting the WISC-III for assessing spatial reasoning ability, but a scan of our review shows modest use of WISC-III scales in studies of music. Apart from Schellenberg, we are not aware of any study in this field that has used the *Full Scale Intelligence* measure, and only two that exploit a significant subset of its major scales⁸. One reason for its limited use is that the WISC-III test battery is time consuming, painstaking to administer, and expensive by norms of research in education. Its publisher, the Psychological Corporation, restricts use of the test to Ph.D. psychologists who have been trained to administer and interpret it. The entire battery requires more than two hours of test time for each subject, and two hours of the trained administrator's time. (Thus Schellenberg's study retaining 132 subjects through the post-test required 528 hours of test administrator time beyond set-up times and testing intervals between subjects.)

Rauscher's early studies (Rauscher, Shaw, Levine, Ky, & Wright, 1994; Rauscher et al., 1997) enlisted the WPPSI-R rather than the WISC-III, and administered four of the Performance sub-test tasks: Object Assembly, Block Design, Geometric Design, and Animal Pegs. Her studies found enhancement only for the *Object Assembly* task as an indicator of spatial reasoning skills in very young children. More than half of the studies assessed by Hetland (2000) in her meta-analysis of 39 music and spatial ability experiments used the Paper Folding and Cutting task from the Stanford-Binet battery (pp. 120-122)⁹.

The full range of WISC-III scales presents analytical opportunities generally not enlisted in the music field. If we look at studies using the WISC-III more generally to assess cognitive functioning, and in particular studies that focus on spatial skills, a tradition of indicators is

⁸ Hetland's (2000) meta-analysis of 35 music and spatial reasoning studies generally conducted in the late 1990s reports no results from the WISC. Sixty-one percent of the reported studies used the Paper Folding and Cutting task from the Stanford-Binet battery.

⁹ The Object Assembly task requires children to assemble cardboard cut-out pieces of a familiar object into a unified whole in the absence of a physical model; the Paper Folding and Cutting task presents subjects with a drawing of a piece of paper that has been folded and cut in several places. The subjects' task is to mentally unfold the paper in order to choose an illustration depicting what the paper would look like after it has been unfolded.

visible. First, professionals involved in the assessment of learning disabilities find useful the distinction between visual-spatial skills on the one hand and verbal skills on the other hand. The Learning Disabilities Association of Ontario advises its members to consider the *Performance IQ* scale of the WISC-III to top the inventory of tests for visual-spatial processing¹⁰. In an excerpt from her book, Bonnell (n.d.) claims that, "...poor *Performance IQ* means a general visual-spatial disability."

Riverside Publishing, publisher of a rival test, the Woodcock-Johnson (WJ) III, aligns spatial-relations measures of the WJ III to three sub-tests in the WISC-III: Block Design, Object Assembly, and Picture Completion. These are three of the five sub-tests in the WISC-III *Performance IQ* scale (excluding Symbol Search and Coding). The Psychological Corporation, publisher of the Differential Abilities Scales (1990), states in its handbook for the DAS that, the DAS spatial cluster and the WISC III Performance (IQ) scale correlated the highest ($r=.82$). Geneticist H. Hirota (2003) referred to the *Performance IQ* scale of the WISC-III as a measure of visual-spatial intellectual ability. Hirota used *Performance IQ* in a recent study of spatial ability markers located on human chromosomes. And in their very recent review of "types of intelligence" enlisted by cognitive psychologists, Phelps et al. (2005) associate the WISC-III's *Performance IQ* with *Gv*, or visual intelligence, and *Verbal IQ* more with generalized intelligence¹¹. To provide a concrete illustration, Gabel (2001), in the Psychological Corporation's WISC Interpretive Guide, discussed *Gv* (visual intelligence) and its mapping onto the Block Design, Symbol Search, and Coding items of the WISC-III – another three of five subscales comprising *Performance IQ*. Gabel suggested that *Gv* is used by physicists, engineers, auto mechanics, architects, carpenters, sculptors, and parts department managers in their jobs. It could also be that musicians use *Gv* to deal with the demands of their instruments and music notation.

Taken together, professional and scholarly usage of the WISC-III *Performance IQ* scale supports its potential value in sifting through the "types of intelligence" that may be influenced by music lessons. In traditional usage, *Performance IQ* is thought to involve capacities largely distinct from the capacities measured by the *Verbal IQ* scale¹². Since *Full Scale IQ* is solely derived from *Performance IQ* and *Verbal IQ*, an imbalance of experimental score gains between *Performance IQ* and *Verbal IQ* might point to specific building blocks of measured general intelligence gains. In the case of music, there is a possibility that IQ gains such as those reported by Schellenberg (2004) came more through advances in visual-spatial processing skills than through gains in verbal skills. In addition, an inquiry into this possibility might suggest mechanisms underlying the increase in *Full Scale IQ* accompanying music lessons in the Schellenberg study.

¹⁰ Learning Disabilities Society of Ontario. Idao.caa/pei/assessment/supporting.php.

¹¹ General intelligence is represented by *Gc*, crystallized intelligence (facts), and *Gf*, fluid intelligence (reasoning with facts).

¹² We should note that *Verbal IQ* and *Performance IQ* are not completely unrelated. In our database, the correlation of pre-test measures of the two scales is about 0.3. As administered to 6 year olds, the WISC-III is administered orally, and all scales would be impacted by children's aural information processing skills.

MATHEMATICS IN THE WISC-III

The *Full Scale IQ* and *Performance IQ* scales do not include a test of mathematics proficiency. An item labeled *Arithmetic* is included in the WISC-III *Verbal IQ* battery, ostensibly because the items depend more on decoding of oral language than success in solving mathematics problems. The student assessments in the Schellenberg experiment went beyond the WISC-III to include the Kaufman Test of Educational Achievement (K-TEA), Comprehensive Form (Kaufman & Kaufman, 1985). This test includes items scaled for mathematics computation (calculation and operations) and mathematics applications (math reasoning and application to problems). These scales present an opportunity to explore another reported impact of music instruction, i.e., its effects on mathematics skills.

MUSIC AND VERBAL VERSUS SPATIAL SKILLS

For our first analyses we compared the effects of music participation on *Verbal IQ* and *Performance IQ* respectively. We first combined the keyboard and voice groups into a single "music" group and the drama and no lessons groups into a single "no-music" control group. We then examined the differences between the combined music group and the combined control group. We next assessed the effects of the keyboard only group on verbal and performance intelligence and compared the keyboard group to the no-lessons control group. The results are shown in Table 2.

**Table 2. Comparisons of WISC III Scale Score Gains:
Music Groups vs. No-music Groups
Verbal IQ, Performance IQ**

Music (Keyboard or voice) vs. No Music (Drama or no lessons)								
Measure	Group	N	Pre-Score	Post-score	Gain-score	Sig. p< ***	Pct. Gain	Effect Size
Verbal IQ	music	62	114.02 12.29*	119.76 14.35	5.74	0.000	5.0%	0.45
	no-music	70	112.9 12.84	115.97 12.24	3.07	0.011	2.7%	
Performance IQ	music	62	51.74 6.87	57.08 10.19	5.95	0.009	10.3%	0.55
	no-music	70	49.99 9.7	53.57 10.71	2.06	0.226	7.1%	
Keyboard vs. No Lessons								
Verbal IQ	keyboard	34	113.2 12.11	117.63 15.56	4.43	0.021	3.9%	0.42
	no-lessons	42	112.56 10.62	115.47 11.34	2.91	0.053	2.6%	
Performance IQ	keyboard	34	50.05 7.13	56.33 9.35	5.8	0	11.5%	0.68
	no-lessons	42	47.89 9.51	51.17 9.01	3.28	0.004	6.8%	

* Standard deviation;

* t-tests for sig. of pre- to post-score gains; Data derived from Schellenberg, 2004.

The upper half of Table 2 displays the results for the music/no-music comparison. There were 62 students in the music group and 70 students in the no-music group – accounting for all subjects for which the study obtained pre- and post-surveys. The second and third numerical columns show the actual pre-scores and post-scores on the *Verbal IQ* and *Performance IQ* scales, along with standard deviations. Pre-test to post-test gain scores are shown along with the statistical significance of score gains.

What do we see in Table 2? First, both groups made significant gains on the *Verbal IQ* and *Performance IQ* scales over the course of their first grade year. This seems indicative of an expected gain on these tests over a school year at the age of six. When we look at the performance of the music vs. no-music groups, raw gain scores cannot be directly compared because *Verbal IQ* and *Performance IQ* are built on different scales – medians of about 100 points for *Verbal IQ* and 50 points for *Performance IQ*. One way to compare score gains is by simply looking at the percentage gains represented by the gain-scores. In this case, it can be seen that both groups gained in percentage terms on both scales. The music group outpaced the no-music group in *Verbal IQ* gains, 5.74 percent as opposed to 3.07 percent. The music group gained 10.3 percent in *Performance IQ* while the no-music group gained 7.1 percent. Based on percentage gain score changes, it appears that the music group made comparatively larger gains in *Performance IQ* than in *Verbal IQ*.

Since the numerical scales differ, the best test for differences in *Verbal IQ* versus *Performance IQ* gain scores is to standardize the gains and to calculate the effect sizes associated with participating in music. This is accomplished by dividing the music group's score gains on the measures by the respective standard deviations of comparison group pre-scores on the same measure. For example the effect size of participating in music on *Verbal IQ* (in comparison to the control group or no-music status) equals the music group's *Verbal IQ* gain (5.74 points) divided by the standard deviation of the no-music group's *Verbal IQ* pre-score (12.84). The effect size is 0.44. An effect size of 0.30 is considered moderate but significant. Effect sizes above 0.50 are considered robust.

The critical comparison for our analysis shows up in relative effect sizes that gauge music's effect on verbal intelligence versus performance (or visual-spatial) intelligence. As shown in Table 2, music participation in this experiment shows an effect size of 0.45 on *Verbal IQ* and a somewhat (but not greatly) larger effect size (0.55) on *Performance IQ*. This supports the contention that gains in *Full Scale IQ* associated with music lessons benefited more from gains in visual-spatial intelligence than in verbal intelligence. This suggests that a specific effect of music lessons on visual-spatial intelligence was important to the outcome of the *Full Scale IQ* analysis, and that spatial reasoning might be considered a mechanism through which music impacts intelligence.

The bottom portion of Table 2 shows an analysis parallel to the one just described exploring music versus no-music in this study: a comparison of the keyboard group, one of the two music sub-groups, to the no-lessons control group (one of the no-music sub-groups). Our interest in the keyboard group grew from research described above often finding that instruction on the keyboard contributes to spatial reasoning skills, possibility due to the spatial layout of the keyboard. The data shown in Table 2 support a claim that the keyboard group experienced more growth in *Performance IQ* than any group studied – including the no-lessons group. Percentage gains in both verbal and visual-spatial scores for the keyboard

group outpaced those of the control group, especially in *Performance IQ*. The effect size on *Performance IQ* (0.68) is larger than the effect size on *Verbal IQ* (0.42). Overall, the disparity favoring visual-spatial development over verbal development is greater for the keyboard group than for the combined music (singing and keyboard) group (a 0.26 point difference versus a 0.10 point difference, for want of a better metric). These data support a contention that the keyboard students in the study contributed significantly to the *Full Scale IQ* gain through disproportionate learning in *Performance IQ*, or the visual-spatial domain.

VISUAL-SPATIAL GAINS FOR WHOM?

Studies of learning such as the ones we reported in this chapter rely mainly on average measures for constructed groups. We decided to explore how music instruction in general and keyboard lessons in particular impacted children with low *Full Scale IQ* pre-test scores. We thus performed tests analogous to the ones shown above in Table 2, but we included only those subjects who had scored at the 50th percentile or below on the *Full Scale IQ* pre-test. These children are likely to suffer more difficulties in school than the average participant in this study. We chose to call this group an *at-risk* sub-sample.

Table 3 shows the results of these analyses. In percentage terms, the music group outscored the no-music group in both *Verbal IQ* and *Performance IQ*. The percent increase in scale scores was higher for *Performance IQ* than for *Verbal IQ*, but the effect size associated with music participation is about the same for verbal and visual-spatial intelligence.

As we did for the whole sample, we also examined the effects of keyboard lessons, as opposed to no lessons at all, for the at-risk sub-sample. As shown in the lower half of Table 3, we found the largest disparity favoring the effects of music instruction on visual-spatial development compared with the effects on *Verbal IQ*. The keyboard group showed 12 percent score gains in *Performance IQ* in contrast to 4.1 percent score gains in *Verbal IQ*. The effect sizes of the keyboard group for both verbal and spatial intelligence are substantial, but a large difference favors effects on visual-spatial intelligence (effect size 0.88 on *Performance IQ* versus 0.55 on *Verbal IQ*).

**Table 3. Keyboard Group versus No-Lessons Control Group:
Comparisons of WISC III Score Gains:
Verbal IQ, Performance IQ, Verbal Composite, and Arithmetic**

Music (Keyboard or voice) vs. No Music (Drama or no lessons)								
Measure	Group	N	Pre-Score	Post-score	Gain-score	Sig. p<__**	Pct. Gain	Effect Size
Verbal IQ	music	4	106.8 9.23**	114.2 12.71	7.4	0.08	6.5%	0.80
	no-music	42	105.8 9.28	110.3 9.68	4.5	0.034	4.1%	
Performance IQ	music	34	48.41 5.68	54.5 9.05	6.09	0.000	11.2%	0.82
	no-music	42	44.79 7.46	49.35 9.82	4.56	0.000	9.1%	
Keyboard vs. No-lessons								
Verbal IQ	keyboard	18	106.78 10.45	111.33 15.26	4.55	0.080	4.1%	0.55
	no-lessons	26	108.27 8.29	111.58 9.11	3.31	0.066	3.0%	
Performance IQ	keyboard	18	47.78 6.06	54.28 8.64	6.5	0.000	12.0%	0.88
	no-lessons	26	45.04 7.39	49.54 8.43	4.5	0.002	9.1%	

Subsample scoring at or below 50th percentile in Full Scale IQ on pre-test (56.7 percent of subjects due to ties).

** standard deviation

*** t-tests for sig. of pre- to post-score gains.

Data derive from Schellenberg, 2004.

AT-RISK VERSUS ALL STUDENTS

It appears that the effects of music on both *Verbal IQ* and *Performance IQ* are higher for the at-risk group (Table 3) than for the consolidated music group. A portion of this general effect is probably due to a natural regression of scores toward the mean. Students in the lowest reaches of a performance distribution on a pre-test are likely to improve their scores more than the average student. Another possible explanation for the disparity is that children with lower spatial ability tend to benefit more from keyboard lessons than other children. For some reason their visual-spatial learning curve is steeper. In any case, the relatively strong effect of keyboard lessons on *Performance IQ* in this sub-sample is an important finding and an issue that has not been attended to in research to date.

MUSIC AND MATHEMATICS

In this final section we turn to our analysis of the effects of music instruction in general as well as the effects of keyboard instruction in particular on mathematics skills. Our approach parallels our assessment of music instruction's effects on *Visual* and *Performance IQ*. We examined standardized gains in mathematics computation and math applications indicated by student performance on pre- and post-test measures from the K-TEA.

We first examined relationships between the music lesson and no-music lesson groups in the experiment. About half of the children were assigned to either keyboard or voice education (music lesson group). The others were assigned to drama lessons or no lessons at all (no-music lesson group). Our comparisons in mathematics learning are based, as above, on standardized gains in average group test scores and effect sizes.

Our main comparisons for music versus no-music groups are shown in the upper half of Table 4. Here it can be seen that all groups made significant gains in math computation and math applications scores. Percentage score gains were in the 9.8 percent to 15.8 percent range, and effect sizes were in the 0.62 to 0.93 range. These gains are generally larger than any effects we saw for treatment and comparison groups on *Visual* or *Performance IQ*. Disproportionate gains in mathematics achievement for all groups probably speak to the fact that math is generally taught every day in the elementary school curriculum and few students fail to progress at some level. The data in Table 4 show that effect sizes in mathematics for the consolidated music groups marginally exceed gains for the no-music group – effect sizes of 0.80 versus 0.62 in math computation and of 0.93 versus 0.87 in math applications. These margins do not attest to dramatic differences in math scores between music and no-music groups, but some link across music learning, spatial skills development, and mathematics learning may be at work. The data more firmly reveal that all groups on average made significant progress between pre- and post- mathematics tests.

Table 4 also displays the results of our analysis of mathematics impacts for keyboard students versus the no-lesson control group. The results resemble what we found for all students¹³. We show 11 to 15 percentage point gains in computation and application scale scores across all groups and very modest differences in music instruction's effect sizes favoring the all-music and keyboard groups. If something is propelling math scores through gains in spatial-temporal skills or through other mechanisms, the valence seems positive. However, additional research is needed to say much more.

A similar story emerges for our final analysis, the impacts of music on mathematics for students who started this experiment scoring in the lower half of the *Full Scale IQ* distribution. We characterized this group above as having higher risk of difficulties in school. Indeed, a comparison between Table 4 (all students) and Table 5 (at-risk sub-sample) shows uniformly lower average math scores for at-risk students, as one indicator of relative preparedness for what lies ahead. As we saw in Table 4, percent score gains in mathematics shown in Table 5 are large for all groups. A very small advantage generally accrues to the music and keyboard groups. An exception shows in the bottom lines of Table 5 where we see

¹³ The keyboard students made up half of the consolidated music groups; thus their respective performance outcomes will be significantly correlated.

that the no-lessons control group gained slightly more than the keyboard group in math applications scores, albeit with nearly identical gains.

**Table 4. Comparisons of Scale Score Gains:
Music Groups vs. No-music Groups
Math Computation: Math Applications**

Music (Keyboard or voice) vs. No Music (Drama or no lessons)								
Measure	Group	N	Pre-Score	Post-score	Gain-score	Sig. p< ***	Pct. Gain	Effect Size
Math Computation	music	62	89.55 16.68	103.69 11.09	14.14	0.000	15.8%	0.80
	no-music	70	90.29 17.63	100.44 10.13	10.89	0.000	11.2%	0.62
Math Applications	music	62	90.27 10.13	99.74 10.22	9.45	0.000	10.5%	0.93
	no-music	70	90.70 10.15	99.56 11.1	8.86	0.000	9.8%	0.87
Keyboard vs No Lessons								
Math Computation	keyboard	30	90.93 17.29	104.43 13.2	13.50	0.000	14.8%	0.80
	no-lessons	36	86.5 16.87	97.75 10.65	11.25	0.000	13.0%	0.67
Math Applications	keyboard	30	90.97 11.68	101.8 11.68	10.83	0.000	11.9%	1.06
	no-lessons	36	88.89 10.22	98.42 10.97	9.53	0.000	10.7%	0.93

* Standard deviation.

** Standardized gains for control groups.

*** t-tests for sig. of pre- to post-score gains.

Data derive from Schellenberg, 2004.

Mathematics scales from the Kaufman Test of Educational Achievement (K-TEA; Kaufman & Kaufman, 1985).

**Table 5. Comparisons of Scale Score Gains:
Music Groups vs. No-music Groups
Math Computation: Math Applications
Subjects w/ Low Pre-Full Scale IQ******

Music (Keyboard or voice) vs. No Music (Drama or no lessons)								
Measure	Group	N	Pre-Score	Post-score	Gain-score	Sig. p< ***	Pct. Gain	Effect Size
Math Computation	music	34	85.18 17.64	101.5 12.21	16.32	0.000	19.2%	0.93
	no-music	42	83.05 17.63	96.67 10.13	13.62	0.000	16.4%	0.77
Math Applications	music	34	86.24 10.53	95.76 9.09	9.52	0.000	11.0%	0.94
	no-music	42	86.74 10.15	95.36 11.1	8.62	0.000	9.9%	0.85
Keyboard vs No Lessons								
Math Computation	keyboard	18	88.67 18.54	102.44 15.43	13.77	0.002	15.5%	0.82
	no-lessons	26	83.05 16.87	95.35 10.65	12.30	0.001	14.8%	0.73
Math Applications	keyboard	18	87.78 10.13	97.28 10.22	9.50	0.000	10.8%	0.97
	no-lessons	26	86.73 9.825	96.46 11.1	9.73	0.000	11.2%	0.99

* Standard deviation.

** Effect size for treatment groups. Standardized gains for control groups.

*** t-tests for sig. of pre- to post-score gains.

**** Subsample scoring at or below 50th percentile on WISC III Full Scale IQ pre-test.

Data derive from Schellenberg, 2004.

CONCLUSION

In this chapter, we reviewed leading research on the extra-musical effects of music learning. This body of research focuses on the cognitive manifestations of music experiences. It consequently also focuses on the possible cognitive effects of music and especially our capacities to think. A preponderance of cognitive studies in music suggest that music instruction's most commonly seen effect is on visual-spatial thinking skills. This conclusion is based on studies of varying music modalities using a variety of research instruments designed to measure visual-spatial skills. Studies also indicate that among music experiences, learning to play the keyboard is prominent among the musical instruments showing effects on spatial thinking. This may be because of the geometric/spatial layout of the keyboard paired with the corresponding geometry and proportionality of written music.

In the latter half of this chapter, we assessed data from a recent high-quality study that concluded that music lessons enhance intelligence (Schellenberg, 2004). Our purpose was to examine this popularized and scientifically justified claim to see if spatial reasoning development was disproportionately responsible for measured growth in general intelligence. This curiosity was of course propelled by the traditions in cognitive music research just described. We also capitalized on an opportunity to explore possible relations between music lessons and student mathematics achievement.

Our instincts were rewarded for the most part. Using *Verbal IQ* and *Performance IQ* measures from the WISC-III—the two scales that account completely for *Full Scale IQ*—we assessed developments of music versus no-music students. In one comparison, we showed that for the consolidated music group (both the keyboard and voice lessons groups together), music participation or learning boosted *Performance IQ* (visual-spatial) more than *Verbal IQ*, with effect sizes 0.55 versus 0.45, respectively. Thus music instruction in this experiment not only boosted general intelligence, but also the overall measure showing increased intelligence was comprised of modestly stronger developments in visual-spatial skills than in verbal skills.

When we turned to keyboard lessons versus no lessons at all, our instincts led us to hypothesize that any contributions to increased intelligence from the keyboard group would favor growth in visual-spatial skills perhaps even more than the keyboard and voice groups combined. Keyboard instruction's effect on visual-spatial skills (effect size 0.68) was in fact stronger than its effect on verbal skills (effect size 0.42). Of the two musical experiences in this experiment, keyboard lessons showed greater influence on spatial skills development. Furthermore, for students scoring low in *Full Scale IQ* at the start of the study, the components of general intelligence gains were balanced between visual IQ and verbal IQ. For the lower IQ keyboard group, however, gains in visual skills outpaced gains in verbal skills by the highest proportion of all of our comparisons.

A general finding of this analysis is that comparative gains in general intelligence reported for music students may be caused more by gains in visual-spatial reasoning skills than by gains in verbal skills. We could stretch this point with an assertion that we did not test: That the importance of music instruction's contribution to spatial skills may be masked though the analytical techniques we used in this research. It is possible that gains in visual-spatial skills for music students contributed to increases in their verbal skills, based on supported contentions that language has a significant spatial-relations component. (Of course things could work the other way around: children may gain more on spatial tests if their language skills have improved.) At any rate, this discussion seems to touch on some underlying mechanisms through which music bears on thinking skills.

We then explored possible effects of music lessons on proficiency in mathematics. In this analysis, we found generally large effect sizes (proficiency gains for all groups). These gains favored all-music and keyboard students over comparison groups, but the differences were small and probably not educationally important. We also performed the same analysis with an at-risk sub-sample of participating students. Contrary to what we observed in comparisons involving all students, the at-risk music groups – all music and keyboard – showed gains in math skills approximating the gains found for the whole sample. We did not find that music lessons improve mathematics achievement. Another relationship in our data presents another

challenge to music-mathematics hypotheses. In our first pass through the data, music showed stronger effects on visual-spatial skills for at-risk students than for the average music student. At the same time, music showed no greater effects on mathematics proficiency for at-risk students than for all music students. Thus we did not manage to detect an advantage in mathematics for music students that might have been mediated by the development of visual-spatial skills.

Finally, we need to remind ourselves of an issue we broached at the start. If one intends to boost IQ scores, verbal or visual, or mathematics proficiency, music would not be the tool of choice. There are certainly learning programs that would reach such goals more efficiently. Nonetheless, it is important to recognize that music has positive cognitive implications. We do not know the duration of the effects of music exposure on children, at least not the effects that have occupied the learning researchers discussed here (i.e., cognitive effects). However, based on present indications, the valence of music experience in the long run is probably positive for many participants and in ways that have not been fully unpacked. The cellist, guitarist, and trumpet player with ten years of lessons can speak to us directly about many more important effects.

ACKNOWLEDGMENT

We are extremely grateful to Dr. E. Glenn Schellenberg for providing us with the data we used in this analysis.

REFERENCES

- Bahr, N., & Christensen, C.A. (2000). Inter-domain transfer between mathematical skill and musicianship. *Journal of Structural Learning and Intelligent Systems*, 14, 187-197.
- Bhattacharya, J., & Petsche, H. (2001). Universality in the brain while listening to music. *Proceedings of the Royal Society of London*, 268, 2423-2433.
- Bhattacharya, J., Petsche, H., Feldmann, U., & Rescher, B. (2001). EEG gamma band phase synchronization between posterior and frontal cortex during mental rotation in humans. *Neuroscience Letters*, 311, 29-32.
- Bilhartz, T.D., Bruhn, R.A., & Olson, J.E. (2000). The effects of early music training on child cognitive development. *Journal of Applied Developmental Psychology*, 20, 615-636.
- Brochard, R., Dufour, A., & Després, O. (2004). Effect of musical expertise on visuospatial abilities: evidence from reaction times and mental imagery. *Brain and Cognition*, 54, 103-109.
- Byrnes, J.P. (1996). *Cognitive development and learning in instructional contexts*. Boston: Allyn and Bacon.
- Chan, A.S., Ho, Y.C., & Cheung, M.C. (1998). Music training improves verbal memory. *Nature*, 396, 128.
- Costa-Giomi, E. (1999). The effects of three years of piano instruction on children's cognitive development. *Journal of Research in Music Education*, 47, 198-212.

- Cranberg, L.D., & Albert, M.L. (1988). The chess mind. In K.L. Obler & D. Fein (Eds.), *The exceptional brain* (pp. 156-190). New York: The Guilford Press.
- Crncec, R., Wilson, S.J., & Prior, M. (2006). No evidence for the Mozart effect in children. *Music Perception, 23*, 305-317.
- Dong, Y., Fukuyama, H., Honda, M., Okada, T., Hanakawa, T., Nakamura, K. et al. (1995). Essential role of the right superior parietal cortex in Japanese kana mirror reading: an fMRI study. *Brain, 123*, 790-799.
- Fuster, J.M. (1995). Temporal processing. *Annals of the New York Academy of Sciences, 769*, 173-181.
- Gardiner, M.F., Fox, A., Knowles, F., & Jeffrey, D. (1996) Learning improved by arts training. *Nature, 381*, 284.
- Gardner, M.F. (1996). *Test of auditory-perceptual skills*. Hydesville, CA: Psychological and Educational Publications.
- Graziano, A.B., Peterson, M., & Shaw, G.L. (1999). Enhanced learning of proportional math through music training and spatial-temporal training. *Neurological Research, 21*, 139-152.
- Gromko, J.E., & Poorman, A.S. (1998). The effect of music training on preschoolers' spatial-temporal task performance. *Journal of Research in Music Education, 46*, 173-181.
- Hammill, D.D., Pearson, N.A., & Voress, J.K. (1993). *Developmental test of visual perception*. Austin, TX: Pro-ed.
- Hassler, M., Birbaumer, N., & Feil, A. (1985). Musical talent and visual-spatial abilities: a longitudinal study. *Psychology of Music, 13*, 99-113.
- Hassler, M., & Feil, A. (1986). A study of the relationship of composition/improvisation to selected personal variables. *Bulletin of the Council for Research in Music Education, 87*, 26-34.
- Hassler, M., Birbaumer, N., & Feil, A. (1987). Musical talent and visual-spatial ability: onset of puberty. *Psychology of Music, 15*, 141-151.
- Hassler, M., & Birbaumer, N. (1988). Handedness, musical abilities and dichaptic and dichotic performance in adolescents: a longitudinal study. *Developmental Neuropsychology, 4*, 129-145.
- Hassler, M., Nieschlag, E., & de la Motte, D. (1990). Creative musical talent, cognitive functioning, and gender: Psychological aspects. *Music Perception, 8*, 35-48.
- Hebb, D.O. (1949). *The organization of behavior: a neuropsychological theory*. New York: Wiley.
- Hetland, L. (2000). Learning to make music enhances spatial reasoning. *Journal of Aesthetic Education, 34*, 179-238.
- Ho, Y.C., Cheung, M.C., & Chan, A.S. (2003). Music training improves verbal but not visual memory: Cross sectional and longitudinal explorations in children. *Neuropsychology, 17*, 439-450.
- Hui, K. (2006). Mozart effect in preschool children? *Early Childhood Development and Care, 176*, 411-419.
- Hurwitz, I., Wolff, P.H., Bortnick, B.D., & Kokas, K. (1975). Nonmusical effects of the Kodály music curriculum in primary grade children. *Journal of Learning Disabilities, 8*, 167-174.

- Ivanov, V.K., & Geake, J.G. (2003). The Mozart effect and primary school children. *Psychology of Music, 31*, 405-413. Rau
- Jausovec, N., & Habe, K. (2004). The influence of auditory background stimulation (Mozart's sonata K. 448) on visual brain activity. *International Journal of Psychophysics, 51*, 261-271. Rau
- Jausovec, N., & Habe, K. (2005). The influence of Mozart's sonata K. 448 on brain activity during the performance of spatial rotation and numerical tasks. *Brain Topography, 17*, 207-218. Rau
- Jeannerod, M., Decety, J., Michel, F. (1994). Impairment of grasping movements following a bilateral posterior parietal lesion. *Neuropsychologia, 32*, 369-380. Rau
- Karma, K. (1982). Musical, spatial, and verbal abilities: a progress report. *Psychology of Music, Special Issue*, 69-71. Ra
- Kaufman, A.S., & Kaufman, N.L. (1983). *Kaufman assessment battery for children*. Circle Pines, MN: American Guidance Service. Ra
- Kilgour, A.R., Jakobson, L.S., & Cuddy, L.L. (2000). Music training and rate of presentations as mediator of text and son recall. *Memory and Cognition, 28*, 700-710. Sai
- Lamb, S.J., & Gregory, A.H. (1993). The relationship between music and reading in beginning readers. *Educational Psychology, 13*, 19-27. Sci
- Leng, X., & Shaw, G.L. (1991). Toward a neural theory of higher brain function using music as a window. *Concepts in Neuroscience, 2*, 229-258.
- Little, W.A. (1974). The existence of persistent states in the brain. *Mathematical Bioscience, 19*, 101-120. Sc
Sc
- McKelvie, P., & Low, J. (2002). Listening to Mozart does not improve children's spatial ability: final curtains for the Mozart effect. *British Journal of Developmental Psychology, 20*, 241-258. Sc
- Mountcastle, V.B. (1978). An organizing principle for cerebral function: the unit module and the distributed system. In G.M. Edelman & V.B. Mountcastle (Eds.), *The mindful brain* (pp. 1-50). Cambridge, MA: MIT Press. Sc
- Orsmond, G.I., & Miller, L.K. (1995). Correlates of musical improvisations in children with disabilities. *Journal of Music Therapy, 32*, 152-166. Th
Th
- Orsmond, G.I., & Miller, L.K. (1999). Cognitive, musical and environmental correlates of early music instruction. *Psychology of Music, 27*, 18-37.0 Va
- Perkins, D.N., & Salomon, G. (1989). Are cognitive skills context-bound? *Educational Researcher, 18*, 16-25. W
- Rauscher, F.H. (2002). Mozart and the mind: Factual and fictional effects of musical enrichment. In J. Aronson (Ed.), *Improving academic achievement: Impact of psychological factors on education* (pp. 269-278). New York: Academic Press. W
- Rauscher, F.H., Shaw, G.L., & Ky, K.N. (1993). Music and spatial task performance. *Nature, 365*, 611. Zi
- Rauscher, F.H., Shaw, G.L., Levine, L.J., Wright, E.L., Dennis, W.R., & Newcomb, R. (1997). Music training causes long-term enhancement of preschool children's spatial-temporal reasoning abilities. *Neurological Research, 19*, 1-8.
- Rauscher, F.H., & Shaw, G.L. (1998). Key components of the "Mozart Effect." *Perceptual and Motor Skills, 86*, 835-841.

- Rauscher, F.H., & Zupan, M.A.(2000). Classroom keyboard instruction improves kindergarten children's spatial-temporal performance: A field experiment. *Early Childhood Research Quarterly, 15*, 215-228.
- Rauscher, F.H., LeMieux, M., & Hinton, S.C. (2005). *Selective effects of music instruction on cognitive performance of at-risk children*. Paper presented at the bi-annual meeting of the European Conference on Developmental Psychology, Tenerife, Canary Islands.
- Rauscher, F.H., & Hinton, S.C. (2006). The Mozart effect: Music listening is not music instruction. *Educational Psychologist, 41*, 233-238.
- Rauscher, F.H., LeMieux, M.M., & Hinton, S.C. (2006). *Quality piano instruction affects at-risk elementary school children's cognitive abilities and self-esteem*. Paper presented at the Ninth International Conference on Music Perception and Cognition, Bologna, Italy.
- Raven, J.C. (1956). *Coloured progressive matrices*. London: H.K. Lewis.
- Raven, J. C. (1986). *Standard progressive matrices*. San Antonio, TX: The Psychological Corporation.
- Sarnthein, J., von Stein, A., Rappelsberger, P., Petsche, H., Rauscher, F.H., & Shaw, G.L. (1997). Persistent patterns of brain activity: an EEG coherence study of the positive effect of music on spatial-temporal reasoning. *Neurological Research, 19*, 107-116.
- Scandura, J.M. (1984). Structural (cognitive task) analysis: a method for analyzing content: Part 2. Toward precision, objectivity and systematization. *Journal of Structural Learning, 8*, 1-28.
- Schellenberg, E.G. (2004). Music lessons enhance IQ. *Psychological Science, 15*, 511-514.
- Schellenberg, E. G. (2005). Music and cognitive abilities. *Current Directions in Psychological Science, 14*, 322-325.
- Schellenberg, E. G., & Hallam, S. (2005). Music listening and cognitive abilities in 10- and 11-year-olds: The Blur effect. *Annals of the New York Academy of Sciences, 1060*, 202-209.
- Schellenberg, E. G.; Nakata, T., Hunter, P.G. (2007). Exposure to music and cognitive performance: Tests of children and adults. *Psychology of Music, 35*(1), 5-19.
- Thorndike, E.L. (1913). *Educational psychology*. New York: Columbia University Press.
- Thorndike, E.L., Hagen, E.P., & Sattler, J.M. (1986). *The Stanford-Binet intelligence scale* (4th ed.). Chicago: Riverside.
- Vaughn, K. (2000). Music and mathematics: Modest support for the oft-claimed relationship. *Journal of Aesthetic Education, 34*, 149-166.
- Wechsler, D. (1989). *Wechsler preschool and primary scale of intelligence-revised*. San Antonio, TX: The Psychological Corporation.
- Wechsler, D. (1991). *Wechsler intelligence scale for children—third edition*. San Antonio, TX: Psychological Corporation.
- Zafranias, N. (2004). Piano keyboard training and the spatial-temporal development of young children attending kindergarten in Greece. *Early Childhood Development and Care, 174*, 199-211.