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Music Exposure and the Development of Spatial Intelligence in Children

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A serious challenge facing music cognition researchers is the problem of how to fit the discipline into traditional theories of child development, theories that do not easily account for the huge range of reasoning and behaviors used by people performing musical activities. In *Frames of Mind*, Howard Gardner (1983) has drawn from a wide body of knowledge to provide us with a new framework for thinking about cognition—a framework that holds a special place for music. Musical ability is seen as its own discrete domain of intelligence, not particularly associated with linguistic, mathematical, or spatial intelligence.

However, despite the fact that music appears to be a distinct area of learning that may be unrelated to other developmental accomplishments of young children, musical abilities and certain spatial abilities do seem to be allied. It seems that musical experiences, perhaps due to neurophysiological mechanisms, can help develop a small but important facet of spatial ability in adults, children, and even in rats. This paper presents my colleagues' and my recent research on the effects of music instruction on a specific type of spatial reasoning, spatial-temporal reasoning, in children.

Neurophysiological Insights

Leng and Shaw's (1991) structured neuronal model of cortex proposes that certain neural firing patterns organized in a complex spatial-temporal code over large regions of cortex are exploited by both musical and spatial reasoning tasks. "We see the brain's innate ability to relate (through symmetry operations) patterns developing in space and time as the unifying physiological mechanism" (Shaw, 1999, p. xv). Based on their model, Leng and Shaw (1991) predicted that music training could strengthen the neural firing patterns used in both music and spatial-temporal tasks through Hebbian (1949) learning principles. Music instruction provided to young children, they proposed, should enhance spatial-temporal task performance.

Knowledge regarding the development and plasticity of the young child's brain (Huttenlocher, 1984; Johnson & Gilmore, 1996; Rakic, 1997) is highly relevant to Leng and Shaw's (1991) hypothesis. At birth, most of the brain's 100 billion neurons are not yet connected in networks. Connections among neurons are formed extremely rapidly in the early years of life as the growing child experiences and forms attachments to the surrounding world. If these synapses are used repeatedly in the child's day-to-day life, they are reinforced and become part of the brain's permanent circuitry. If they are not used repeatedly, or often enough, they are gradually eliminated during the second decade of life (Huttenlocher, 1984). In this way, as a child grows, an overabundance of connections gives way to a complex, powerful system of neural pathways. How the child thinks and learns appears to depend largely on the nature and extent of these pathways.

Rauscher, Shaw, Levine, & Wright, 1993. Ten 3-year-old children enrolled in either a middle-income school or a school for at-risk children participated. We pre-tested spatial-temporal and spatial recognition skills using a sub-test from an age-standardized intelligence test (Wechsler Preschool and Primary Scale of Intelligence-Revised). We then provided music training for nine months, and post-tested their spatial reasoning skills. Findings indicated that the spatial-temporal scores of the children following music training improved by an average of 47% compared to national norms. The at-risk children improved by 91%. Spatial recognition scores did not improve. However, the small sample size and lack of control groups restricted us from drawing strong conclusions from these data.

Rauscher, Shaw, Levine, Ky, & Wright, 1994. Nineteen 3-year-olds (music group) received 8 months of music lessons; 14 3-year-olds (control group) received no lessons. We pre-tested the children's spatial-temporal and spatial recognition skills, again using the WPPSI-R. The children were then provided with weekly piano keyboard lessons and daily singing sessions for 8 months. We then post-tested the children's spatial skills. The music group's spatial-temporal scores were significantly higher following training compared to the control group. Again, spatial recognition scores did not improve for either group.

One might reasonably argue that the improvement of scores for the music group is because of a Hawthorne effect. (The Hawthorne Effect is the generalization that anything new works: new programs, new curricula, etc.—at least for a little while. The existence of the Hawthorne Effect makes a true evaluation of any new program a difficult affair.) We believed that the lack of significant improvement of the *other* tasks (the spatial recognition tasks) made this alternative explanation unlikely. However, we increased our fund-raising efforts and were finally able to include a group of children who received computer instruction, rather than music instruction, to control for this possibility.

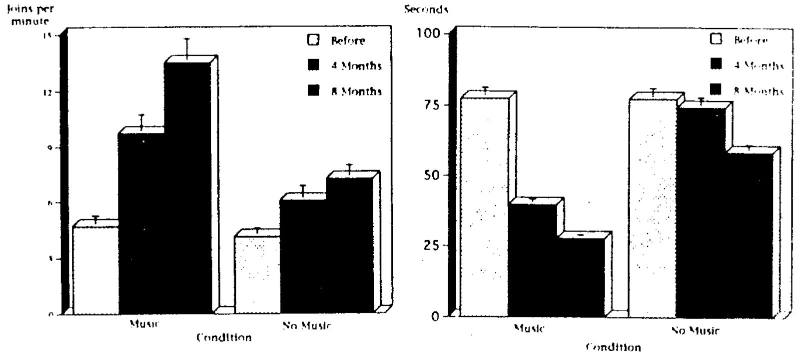
Rauscher, Shaw, Levine, Wright, Dennis, & Newcomb, 1997. We pre-tested the spatial-temporal and spatial recognition skills of 78 children using the WPPSI-R, and then assigned them to one of four conditions. Thirty-four children received 8 months of piano lessons along with casual daily singing; 10 children participated in the singing sessions only; 20 children received computer lessons; 14 children received no lessons. Keyboard and computer lessons were matched in frequency and duration. Post-testing revealed that the spatial-temporal task scores of the keyboard group were significantly higher compared to those of the children who received computer lessons, casual singing, or no lessons. The scores of the children in these three latter groups did not differ. Spatial recognition scores did not improve for any group.

Ongoing research. Our next goal was to determine if the effects we were finding with preschoolers through private instruction could be achieved in the chaotic setting of the public school classroom using group instruction. The study outlined below reports data showing that kindergarten children who were exposed to keyboard lessons in a hectic classroom environment improved significantly on two spatial-temporal tasks administered. A test of pictorial memory did not improve following lessons.

Rauscher & Zupan, in press. Sixty-two Kindergarten children participated. Thirty-four children received 8 months of keyboard lessons (music group); 28 children received no lessons (no lessons group). We pre-tested the spatial-temporal skills and pictorial memory of all children, and then provided bi-weekly 20-min keyboard lessons to the music group in groups of eight to ten. The lessons continued for 8 months. We post-tested the children at four month intervals. The spatial-temporal task scores of children who received music training were 48% higher after eight months of instruction than those of the children who did not receive music training. Pictorial memory scores did not differ.

Further details of the Rauscher and Zupan (in press) study are given to provide context for a follow-up study reported next. Four kindergarten classrooms from two public elementary schools took part. The curriculum, developed by Lori Custodero of Columbia University Teachers College, consisted of (a) movement to the musical material based on pitch and rhythmic structure; (b) association of fingers and numbers (for identification purposes); (c) creative projects; (d) association of keyboard geography with sung musical pitches; (e) playing tunes by ear; (f) playing tunes by reading simple contours, leading to music literacy; (g) ear training and improvisation games (rhythmic and melodic).

Prior to the instruction, all children were pre-tested with two spatial-temporal tasks, Puzzle Solving and Block Building, and one other task, Pictorial Memory. As before, we predicted improvement only for the spatial-temporal tasks, Puzzle Solving and Block Building. We did not expect Pictorial Memory to improve as a function of lessons. There were two post-testing sessions, spaced four months apart. Figure 1 presents the data for the two spatial-temporal tasks, Puzzle Solving and Block Building. To obtain a score for the Puzzle Solving task we divided the number of correctly joined puzzle pieces by the number of minutes taken to complete each puzzle. The higher the score, the better the performance. For Block Building we tabulated the total number of seconds taken to complete the structure. The lower the score, the better the performance. For both tasks, the children who received the lessons scored significantly higher than the children who did not. After training, their scores had improved significantly.



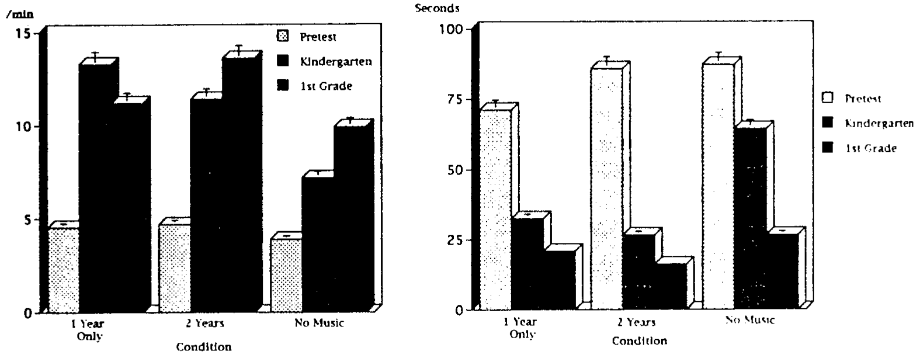
Puzzle solving

Block building

Figure 1. Puzzle solving and block building scores for the music and no music conditions before, four months, and eight months after treatment.

These data indicate that kindergarten children who were provided with just 4 months of lessons scored 42.5% higher than the children who did not receive lessons. After 8 months the average difference between the groups for these tasks was 48%. The music group improved by 63% following lessons, whereas the no music group improved by only 33.5%. As predicted, the difference between the scores on the Pictorial memory task for the two groups of children was not significant.

The following year the school district continued to provide keyboard instruction to some children in the first grade. Logistics of classroom assignment left us with three groups of children to re-test. Fourteen children had received music instruction for one year, and were then graduated to a first-grade classroom in which the instruction was not provided (one year only group). Seventeen children received the keyboard instruction for 2 years, in both kindergarten and first grade (2 years group), and seventeen children received no music instruction at all (no music group). All children were re-tested after completing the first grade. Figure 2 shows the data for the Puzzle Solving and Block Building tasks.



Puzzle solving

Block building

Figure 2. Puzzle solving and block building scores for children in the 1-year, 2-year, and no music training conditions.

Analyses of variance followed by Scheffé tests revealed significant differences between the groups. The Puzzle Solving scores of the children who received music training in kindergarten only (one year only group) were significantly lower when tested one year after their lessons were terminated. In fact, after one year their scores were not significantly different from those of the children who received no lessons. However, the scores of the children who continued lessons through the second year (2 years group) increased significantly. Finally, the children who received no lessons showed only the improvement one would expect from age.

The Block Building task showed no significant improvement for either the one year only or the two years groups, although the trends were in the expected direction. This may be due to a ceiling effect. As with the Puzzle Solving task, the no music group continued to improve with age. These data suggest that the effects found by Rauscher & Zupan (in press) for Block Building were not maintained. We hope to follow these children over a period of years using different age-appropriate tests.

A similar study was conducted at Franklin Elementary School in Oshkosh, Wisconsin. To control for the Hawthorne Effect, this study compared a keyboard training group to a control group of children who received special reading instruction instead of no lessons. The dependent variable was a computer animated software program (FISH™) designed by Matthew Peterson of the University of California Berkeley to measure proportional reasoning.

Participants were 66 Kindergarten children. We pre-tested the children's proportional reasoning skills using a computer animated assessment program (FISH™). We then provided weekly 40-min keyboard lessons to 35 children in groups of eight to ten. 31 children received the animated reading instruction for eight months. We then post-tested all the children. The data are graphed in Figure 3 (Rauscher, 1999).

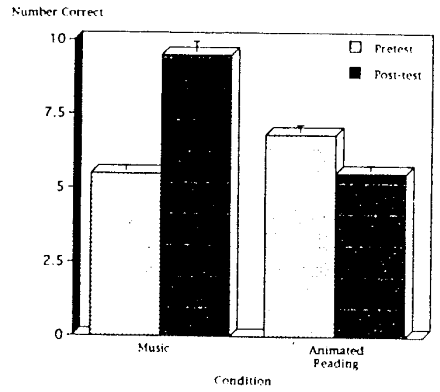


Figure 3. STAR™ scores for children in music and animated reading conditions.

An analysis of covariance performed on the children's post-test scores (with pre-test entered as the covariate) found a main effect for condition ($F_{(1,\,63)} = 11.31$, $p = .001$). Scheffé tests revealed that the children in the music group scored significantly higher following the music instruction, whereas those in the reading group actually scored lower, although the decrease was not significant. After the instruction, the music group scored 42% higher than the reading group. This study is currently being replicated and extended.

The enhancing effect of music instruction on spatial-temporal task abilities in young children has been found by other researchers as well (Costa-Giomi, 1998; Graziano, Peterson, & Shaw, 1999; Gromko & Poorman, 1998; Hurwitz, Wolff, Bortnick, & Kokas, 1975; Mallory and Philbrick, 1995), and we are confident that these effects are robust. However, very little is known regarding the nature of the effect. One approach to examining the nature of the relationship between music and spatial-temporal reasoning is to analyze the cognitive requirements that they share. According to Whohlwill (1973), the most fruitful new efforts of this sort begin by offering descriptions of dimensions—in this case, those of the cognitive skills used in musical performance and in spatial-temporal reasoning, as found in the tasks which were enhanced.

Researchers have proposed several theories to describe the cognitive skills involved in music and in other abilities (Dillon & Sternberg, 1986; Perkins, 1989; Serafine, 1988). Space limitations do not permit an extensive review of these theories. My approach to the problem focuses on extending Serafine's (1988) analysis of the cognitive skills in music to an analysis of spatial-temporal skills. In brief, Serafine describes *temporal processes* (succession and simultaneity) and *nontemporal processes* (closure, transformation, abstraction, and hierarchical levels) as the central measures of the cognitive skills in music. I would add mental imagery as a skill that is also essential to musical performance.

The goals of the ongoing study presented below are to determine if music training can significantly improve the abstract reasoning of economically disadvantaged preschoolers, and to understand why spatial-temporal tasks improve after music lessons whereas other spatial tasks do not. Data are being analyzed from the first 2 years of a 5-year study currently being conducted at 10 Head Start sites located throughout northeast Wisconsin.

Head Start is a federal local matching grant program intended to improve the skills of economically disadvantaged children, so that they can begin schooling on an equal footing with their more advantaged peers. The program began in 1964 as part of the War on Poverty, and it now serves over 700,000 children in predominantly part day programs, or roughly 30% of eligible 3- to 5-year-olds. Most recently, President Clinton has proposed increasing the number of children served to 1 million by the year 2000.

The 5-year study has three main goals: (a) to identify the specific cognitive processes that are enhanced by music training; (b) to determine the properties of the music training that are responsible for these effects; (c) to determine the extent, durability and generalizability of these effects. To address the first goal, during the first 2 years of the study we assessed the tasks on which children display enhanced performance after piano keyboard training. We tested an extremely broad array of cognitive abilities, started providing piano versus computer versus no lessons, and are in the process of re-testing the children's cognition. The second 2 years of the study will address the second goal. We will vary the type of music training the children receive by providing them with keyboard lessons, rhythm instrument lessons, or singing lessons. And finally, toward the last goal, we will follow the children into their public schools, re-test them, test their middle income peers, and assess academic achievement. Over 5 years the study will involve over 400 Wisconsin children. We have completed the first 2 years of the study (Rauscher & LeMieux, 1999).

We began by pre-testing 120 three-year-old Head Start children's spatial abilities and musical achievement. By the end of the second year of the study, we had lost 32 children to attrition, leaving us with 87 children to re-test. Of these, 32 were randomly assigned to a keyboard group, 29 received computer instruction, and 26 received no special training for a period of 48 weeks. The instruction was provided individually at the Head Start schools. We then re-tested all the children.

We used several age-standardized tests: The Kaufman Assessment Battery for Children (KABC), the Developmental Test of Visual Perception, the Test of Auditory Perceptual Skills, the WPPSI, which we had used earlier, and Ed Gordon's Primary Measures of Music Audiation. We have thus far analyzed only the data from the KABC, of which we administered all sub-tests appropriate for 3-year-olds, totaling nine:

1. The **Hand Movements** task requires the person to copy a precise sequence of taps on the table with the fist, palm, or side of the hand. It measures aspects of motor functioning. Success is usually contingent upon a good attention span and concentration.
2. The **Number Recall** task measures the child's ability to repeat in sequence a series of numbers spoken by the examiner.
3. The **Magic Window** task is a spatial-temporal task. It measures the ability to identify and name an object whose picture is rotated behind a narrow slit , so that the picture is only partially exposed at any given point in time. It supposedly measures cerebral hemispheric integration, because it involves a complex integration of spatial information presented temporally.
4. The **Face Recognition** task involves selecting from a group photograph the one or two faces that were exposed briefly on the preceding page.
5. **Gestalt Closure** measures the child's ability to mentally "fill in the gaps" in a partially completed inkblot drawing, and to name and describe the drawing. It measures the child's ability to convert an abstract stimulus into a concrete object
6. **Expressive Vocabulary** measures the child's ability to state the correct name of objects pictured in photographs.
7. **Faces and Places** has the child naming a fictional character or place, such as Snow White, as seen in a photograph.
8. The **Arithmetic** sub-test demonstrates the child's knowledge of numbers and mathematical concepts, counting and computational skills, and other school-related math abilities.
9. The **Riddles** sub-test has the child infer the name of a concrete or abstract concept when given a list of its characteristics.

Preliminary analyses revealed that four of the sub-tests we administered, Magic Window, Gestalt Closure, Hand Movements, and Arithmetic, improved significantly following music training. These data are graphed in Figure 4. Five sub-tests, Number Recall, Face Recognition, Expressive Vocabulary, Faces and Places, and Riddles did not improve significantly.

Three of the tasks that did improve following training, Magic Window, Gestalt Closure, and Arithmetic, lend themselves remarkably well to Serafine's (1988) analysis of musical reasoning, particularly regarding the *nontemporal* processes of closure, transformation, and abstraction. (Improvement of the Hand Movements task may be due to enhanced motor control produced by the music instruction.) The puzzle tasks that were enhanced in previous studies also involve these processes, as well as the *temporal* process of succession she describes. These tasks also rely heavily on mental imagery skills. I suggest that it is these abstract qualities that make spatial-temporal tasks susceptible to enhancement through music training.

The tasks that failed to improve following music instruction do not lend themselves well to her analysis. Although Leng and Shaw's (1991) neural model of higher brain function provides a viable neurophysiological explanation for the transfer effects we are observing, I suggest that Serafine's model (1988) provides a useful framework for understanding the cognitive mechanisms involved. We anticipate our forthcoming analysis of the other cognitive and perceptual tests we administered to yield a better understanding regarding the nature of these transfer effects.

We suggest that the following (tentative) conclusions may be drawn from the studies presented here:

1. Music instruction enhances spatial-temporal abilities in children.
2. The effects are found for children as "old" as five years, perhaps older.
3. One year of instruction is probably not enough for long-term-enhancement
4. The effects in young children may be limited to spatial imagery tasks which can be described by the terms Serafine (1988) used to describe the *temporal* and *nontemporal* processes of musical knowledge.

I conclude with some final thoughts on what these types of studies might mean for music advocacy, followed by a quote from a source unknown to me.

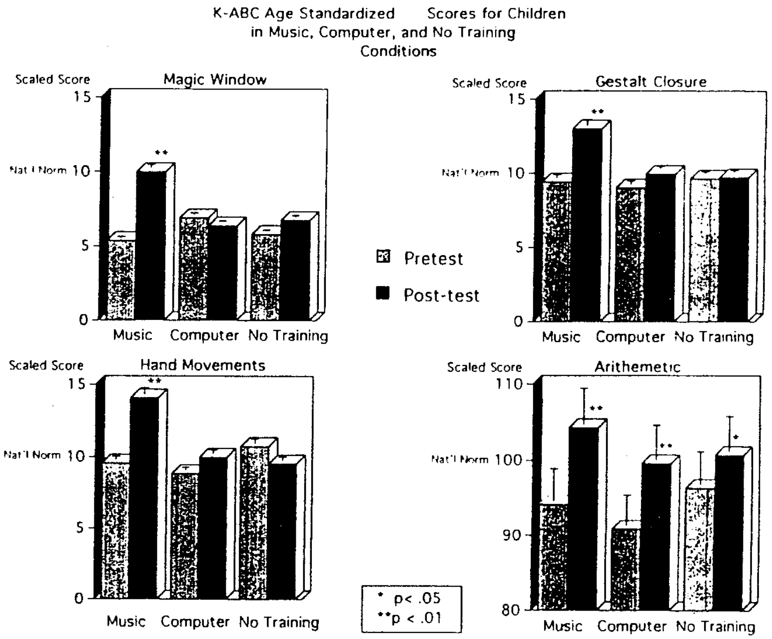


Figure 4. Magic Window, Gestalt Closure, Hand Movements, and Arithmetic scores for children in music, computer, and no training conditions.

> The recent flurry of excitement over the extra-musical benefits of music instruction comes at a time when public school administrators are being forced to justify their public school music programs in order to prevent these programs' annihilation. These studies are sometimes being cited to support the claim that music is important. The thinking is that if music instruction can be shown to have extra-musical benefits, then perhaps school boards will keep their music programs around a bit longer, in the hope that these programs will improve their students' scores in other academic areas.
>
> Although I feel strongly that it is at the least disgraceful and at worse dangerous to have to justify music's inclusion in the public school curriculum by citing *only* its extra-musical benefits, I suggest that an argument in favor of music in the curriculum based *only* on its artistic benefits is equally dangerous. Such an argument is going to seem absurd to most administrators, faced with the budget cuts that they are faced with these days, and is sadly ineffectual. Fewer than 25% of all 8th-grade students participate in music making activities of any kind, including singing (R. Morrison, personal communication, March 5, 1999).

Although many music educators and others are outraged (and rightly so) that the justification for music may lie in research revealing its extra-musical benefits, I believe that to exclude these studies from discussions arguing for music in the schools is to "cut off one's nose to spite one's face." Even worse, to ignore such findings is to do a disservice to the children whose lives will be affected when music programs are eliminated. Economically disadvantaged children, whose caregivers can often afford neither the time nor the money to provide their children with music instruction, stand to lose the most from the elimination of school music programs. Yes, there is much more research needed to provide converging evidence and no, music is not a panacea for poor academic achievement. However, it seems clear that music has benefits to intellectual development that transcend music itself. I suggest that music education is important for optimal development, and that we use all available information to ensure a quality education for our children.

> Whether by voice or by instrument, musical performance requires physical control and precision of a high order. A child working at mathematics or a language can sit back, mentally, for minutes before facing difficulty. The same child, singing or playing a part, must both obey exactly and artistically the present behests of the music, and at the same time think ahead to prepare himself to deal equally faithfully with what is coming. In no other subject is a child called upon to make four or five decisions a second and act on them continuously for such stretches of time. This combination of constant, continuous vigilance and forethought with ever-changing physical responses constitutes an educational experience of unique value. Moreover, by its nature and traditions, the art lends itself more readily than most activities to the pursuit of excellence, to which there is no nobler aim of education.
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> —Author unknown

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