

Classroom Keyboard Instruction Improves Kindergarten Children's Spatial-Temporal Performance: A Field Experiment

Frances H. Rauscher

Department of Psychology, University of Wisconsin Oshkosh

Mary Anne Zupan

School District of Kettle Moraine

The purpose of this study was to determine the effects of classroom music instruction featuring the keyboard on the spatial-temporal reasoning of kindergarten children. Sixty-two kindergartners were assigned to one of two conditions, keyboard or no music. All children were pretested with two spatial-temporal tasks and one pictorial memory task. The keyboard group was provided with 20-min lessons two times per week in groups of approximately 10 children. Children were then retested at two 4-month intervals. The keyboard group scored significantly higher than the no music group on both spatial-temporal tasks after 4 months of lessons, a difference that was greater in magnitude after 8 months of lessons. Pictorial memory did not differ for the two groups after the lessons. These data support studies that found similar skills enhancements in preschool children, despite vast differences in the setting in which the instruction occurred. The results have strong implications for school administrators and educators.

Strongly held beliefs among music educators about the benefits of music instruction for young children are supported by anecdotal reports but less clearly by data. Recently, however, studies have demonstrated that preschool children provided with individual music instruction score significantly higher on tests measuring spatial-temporal abilities than do children provided with computer instruction (Rauscher, Shaw, Levine, Wright, Dennis, & Newcomb, 1997) or no lessons

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Direct correspondence to: Dr. Frances H. Rauscher, Department of Psychology, University of Wisconsin Oshkosh, 800 Algoma Boulevard, Oshkosh, WI 54901; Phone: (920) 424-7172; E-mail: rauscher@uwosh.edu.

(Costa-Giomi, 1999; Gromko & Poorman, 1998; Mallory & Philbrick, 1995; Rauscher, Shaw, Levine, Ky, & Wright, 1994; Rauscher et al., 1997). The purpose of this study was to extend these findings to kindergarten children in an elementary public school setting. The findings will provide information relevant to pedagogical decisions and help policymakers prioritize investments among competing curricula.

Spatial Ability

A well-developed spatial ability has several advantages. Arnheim (1969) argued that our perceptions of the world underlie and constitute our most important cognitive processes. As he put it, "The remarkable mechanisms by which the senses understand the environment are all but identical with the operations described by the psychology of truly productive thinking in whatever area of cognition takes place in the realm of imagery" (p. v). Arnheim (1969) further suggested that we are unable to reason clearly about an idea for which we do not possess a mental image. Thus, spatial abilities are relevant to decision making (Johnson-Laird, 1983). A more liberal view would hold that spatial abilities enable scientific and artistic thought (Gardner, 1983, 1993). In either case, children with adequate spatial abilities are more likely to function successfully in their lives and as adults.

The term "spatial cognition" is broadly defined as a specific type of mental processing involving objects that exist in space. Although several subcategories of spatial ability have been documented (Elliot, 1980; Elliot & Smith, 1983; Nicolopoulou, 1988), there is little consensus among psychologists as to how to best classify spatial skills (McGee, 1979). Neurologists examining spatial deficits in adults have shown that the spatial factor is not a unidimensional concept, but includes spatial perception, memory, operations (e.g., rotation or reflection of spatial representations), and construction (putting the parts of an object together to create a whole) (Barlow, 1961; Biederman, 1987; Kritchevsky, 1988; Newsome, Britten, & Movshon, 1989). It thus seems that spatial ability is an amalgamation of loosely related components whose exact number and definition are still under investigation.

Studies exploring the effects of music on spatial abilities point to a dichotomous classification of spatial abilities consisting of *spatial-temporal* processes and *spatial recognition* (Rauscher & Shaw, 1998; Rauscher et al., 1994, 1997). Spatial-temporal processes are used in tasks that require combining separate elements of an object into a single whole by arranging objects in a specific spatial order to match a mental image. Rauscher and Shaw (1998) suggested that spatial-temporal tasks require both spatial imagery and the temporal ordering of objects, abilities they propose are necessary for proportional reasoning used in mathematics and scientific endeavors. This component is distinguished from spatial recognition, which requires the individual to recognize and classify physical similarities of spatial objects (Rauscher & Shaw, 1998; Rauscher et al., 1994, 1997). Neither spatial imagery nor temporal ordering is required of tasks relying solely on spatial recognition.

Knowledge gained from musical training seems to be relevant to spatial-temporal processes (Gromko & Poorman, 1998; Mallory & Philbrick, 1995; Rauscher et al., 1994, 1997), perhaps because the elements of a musical piece are organized both spatially and temporally. Playing a melody involves reconstructing a pattern in which the elements, the notes, are organized in a highly specialized spatial-temporal code. The overlap of skills required for music and spatial cognition may form the basis for what Tunks (1992) refers to as cross-sensory perception and response, which involves "relating information entering through one sense mode to analogous information in another mode" (p. 443). Perhaps the knowledge gained through music training transfers to spatial-temporal task performance.

Theoretical Background

Howard Gardner's (1983) theory of multiple intelligences challenges the widely held belief that intelligence can be reduced to a single quotient. Gardner proposes the existence of at least eight "intelligences," including musical intelligence and spatial intelligence, and provides converging evidence for the uniqueness of these domains. An ongoing study with Head Start children supports Gardner's theory: Musical aptitude and spatial reasoning scores of 3- and 4-year-old children were not correlated in pretests (Rauscher, 1999), suggesting the independence of these two intelligences. Although it might seem that research demonstrating enhancement of spatial abilities through music instruction runs contrary to Gardner's (1997) theory, Gardner himself asserts that "music may be a privileged organizer of cognitive processes, especially among young people" (p. 9). This interpretation permits one to embrace the concept of autonomous intelligences as well as the possibility that experience in one domain may influence performance in another.

The cortical model of Shaw et al. provides a neuroscientific framework for the relationship between music and spatial cognition (see, for example, Leng & Shaw, 1991). Shaw's structured neuronal model 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. According to the model, music training strengthens these common neural firing patterns through Hebbian (Hebb, 1949) learning principles. Several studies examining electroencephalogram (EEG) provide support for this model (Hughes, Daaboul, Fino, & Shaw, 1998; Rideout & Laubach, 1996; Sarnthein, von Stein, Rappelsberger, Petsche Rauscher, & Shaw, 1997). Leng & Shaw's (1991) model, taken together with children's early sensitivity to music (Gardner, 1983; Krumhansl & Jusczyk, 1990; Olsho, Schoon, Sakai, Turpin, & Sperduto, 1982; Papousek, 1982) and knowledge about the plasticity of the child's brain (Rakic, 1997) suggests that musical training may affect the development of neural pathways relevant to abilities that are influenced by environmental stimulation, such as certain spatial abilities (Rakic, 1997; Rosenzweig & Bennett, 1996). Specifically, Leng and Shaw (1991) proposed that music instruction provided to young children should enhance spatial-temporal task performance.

Empirical Studies

Studies exploring the relationship between music and spatial abilities have focused on correlations between the two cognitive domains or have compared the spatial scores of musicians and nonmusicians (Barret & Barker, 1973; Hassler, Birbaumer, & Feil, 1985; Kalmár, 1982; Manturzewska, 1978). These studies have generally found that individuals with musical talent or training score higher on spatial tasks. Unfortunately, although correlational studies can suggest the existence of a relationship, they cannot determine the cause. Recent studies have investigated the causal nature of the relationship by actually implementing the music lessons to a random sample of children. For example, Rauscher et al. (1997) provided 3-year-old children with 6 months of individual piano keyboard lessons, casual group singing sessions, computer lessons, or no lessons. Spatial-temporal and spatial recognition tasks were administered before and after instruction began. Although the pretest scores of the children in the four groups did not differ, the posttest spatial-temporal scores of the keyboard group were significantly higher than those of the other groups after the lessons. Spatial recognition scores did not improve. Similarly, Costa-Giomi (1999) found that the spatial scores of 9-year-old children who were provided with 2 years of private keyboard lessons were significantly higher than those of children who did not receive the lessons. Gromko and Poorman (1998), Mallory and Philbrick (1995), and Rauscher et al. (1994) found similar results with 3- to 5-year-old children. And finally, an intriguing study performed by Gardiner, Fox, Knowles, and Jeffrey (1996) found that first- and second-grade children who received 7 months of supplementary music and visual arts classes achieved higher standardized mathematics scores than did children who received the schools' typical music and arts training. However, because the two treatments were initiated together it is difficult to determine which intervention caused the improvement.

Although the effects of private keyboard instruction on spatial task performance have been previously established (Costa-Giomi, 1997; Gromko & Poorman, 1998; Mallory & Philbrick, 1995; Rauscher et al., 1994, 1997), no studies have examined whether these effects are sustainable in the turmoil of a public school kindergarten classroom in which groups of children simultaneously engage in either music instruction or other activities. The aim of the present study was to assess the effect on spatial-temporal task performance and pictorial memory of keyboard lessons provided to kindergarten children in a group school setting compared with children who did not receive the lessons. We predicted that the keyboard groups' spatial-temporal scores would improve significantly more than those of the no music group, and the two groups' memory task scores would not differ. Although sex differences in spatial test scores have frequently been reported, with boys scoring higher than girls on spatial tests (e.g., Halpern, 1992; Linn & Peterson, 1985), previous studies with preschoolers found no differences between boys' and girls' spatial-temporal task scores after music instruction (Gromko & Poorman, 1998; Mallory & Philbrick, 1995; Rauscher et al., 1994, 1997). A further goal of this study was to determine whether the spatial-temporal scores of kindergarten children also fail to demonstrate significant sex effects.

Table 1. Distribution of Children in Groups and Schools

School	Group	
	Keyboard	No music
	<i>n</i>	<i>n</i>
Wales Elementary	18	9
Magee Elementary	16	19

METHOD

Participants

Sixty-two middle-income kindergarten children (36 boys and 26 girls) of mixed ethnicity attending four kindergarten classes at two Midwestern public elementary schools participated. The children ranged in age from 5 years, 1 month to 6 years, 1 month at the start of the study.

Procedure

Children were assigned to one of two groups, keyboard ($n = 34$) or no music ($n = 28$). Random assignment was not possible because of logistics and the school administrators' need to keep classes intact. Table 1 shows the assignment of students in the two participating schools to experimental and control groups. A music specialist visited each classroom to administer 20 min keyboard lessons to the keyboard group two times per week. Ten Kawai XG130 keyboards (Hamamatu, Japan) were arranged in a row against one wall of the classroom. The children assigned to the no music group were engaged in journaling by their kindergarten teacher in a separate area of the classroom during lesson time.

Instruction

The children in the keyboard group participated in groups of approximately 10. In a typical lesson, the music specialist assembled the children in a semicircle on the floor away from the keyboards to sing and move to the previous week's keyboard composition. This was followed by singing and moving to the compositions of the current and subsequent weeks, leading to a brief discussion of keyboard hand position. The children were then seated individually at the keyboards to play the previous week's piece alone and in ensembles, followed by an introduction to a new composition accompanied by rhythmic clapping and solfege, culminating in keyboard performance. These activities were interspersed with ear training, notation, rhythm, improvisation, interval, and dynamic exercises. The lesson ended with a review of the day's activities and repertoire. The children assigned to the keyboard group were encouraged to play the keyboards throughout the day. The children in the no music group were not permitted access to the keyboards.¹

Testing

Prior to the instruction, all children were pretested with two tasks, Puzzle Solving and Pictorial Memory, taken from the McCarthy Scales of Children's Abilities (McCarthy, 1972), and one task, Block Building, taken from the Learning Accomplishment Profile Standardized Assessment test (LAP-D) (*Learning Accomplishment Profile*, 1992). The children were tested individually at their schools.

The Puzzle Solving task, a spatial-temporal task, consisted of four items of increasing difficulty. To successfully complete each item the child was required to arrange cardboard pieces of a puzzle to create a familiar object. As with the Object Assembly task used in previous studies (Gromko & Poorman, 1999; Mallory & Philbrick, 1995; Rauscher et al., 1994, 1997), the child's task was to join the puzzle pieces together in particular orders to match a mental image. This task contains both elements required for spatial-temporal reasoning—the formation of a mental image and temporal ordering (Rauscher & Shaw, 1998). The Block Building task, also a spatial-temporal task, consisted of two items. The child was required to reproduce from memory a simple stair-step structure previously created by the test administrator from 10 1-inch blocks. Both mental image formation and temporal ordering are also required for this spatial-temporal task. Finally, the Pictorial Memory task (six items) required the child to recall and identify previously viewed picture objects. A test of visual memory, this task required neither mental image formation nor temporal ordering.

Testing was conducted following procedures specified by the McCarthy (1972) and LAP-D (*Learning Accomplishment Profile Standardized Assessment*, 1992) test manuals. Testing sessions lasted approximately 15 min and were carried out at the schools before lessons and again at two subsequent 4-month intervals, totaling three testing sessions altogether. The keyboard lessons commenced immediately following pretesting. Thus, the final testing session occurred 8 months after the keyboard group's first lesson. Testing was conducted by M. A. Zupan and a colleague blind to the experimental hypotheses and condition assignment.²

Scoring

Puzzle Solving The number of correctly joined puzzle pieces was divided by the number of minutes taken to complete each puzzle within a specified time limit for a dependent measure of joins per minute.

Block Building The total number of seconds taken to complete the structure was recorded. A maximum of 120 sec was permitted. Children who did not complete the structure received a score of 120.

Pictorial Memory The total number of pictured items recalled out of a total of six items was recorded.

Table 2. Mean Task Scores and Standard Deviations for Keyboard ($n = 34$) and No Music ($n = 28$) Groups

Group	Task					
	Puzzle Solving ^a		Block Building ^b		Pictorial Memory ^a	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Keyboard						
Pretest	4.52	3.05	77.68	48.76	3.32	1.09
4 months	9.17	4.97	39.74	38.46	4.26	0.86
8 months	11.97	6.02	27.72	29.67	4.82	1.24
No Music						
Pretest	3.93	2.26	77.66	44.70	3.79	1.20
4 months	5.75	3.26	74.54	48.29	3.50	1.35
8 months	6.87	3.63	58.70	45.49	4.36	1.06

Notes: ^a The higher the score is, the better the performance.

^b The lower the score is, the better the performance.

RESULTS

Means and standard deviations for all variables are presented in Table 2. An α level of 0.05 was used for all statistical tests. The first set of analyses focused on the group factors that may have predicted the skills enhancements found. Because the children's scores on the Puzzle Solving and Block Building tasks were significantly correlated (pretest: $r = -0.25$, $p \leq .05$; 4 months: $r = -0.54$, $p \leq .01$; 8 months: $r = -0.49$, $p \leq .01$),³ a multivariate analysis of variance (MANOVA) with sex (boy, girl) and group (keyboard, no music) as between-subject factors, and time (pretest, 4 months, 8 months) as a within-subject factor was performed on the three dependent measures. We found significant multivariate main effects for group ($\eta^2_{(3,56)} = 0.20$, $p < .005$) and time ($\eta^2_{(6,53)} = 0.86$, $p < .001$) and a significant interaction between group and time ($\eta^2_{(6,53)} = 0.27$, $p < .009$). There was no significant main effect for sex ($\eta^2_{(3,56)} = 0.03$, $p > .05$), and no other significant interactions were found.

We next performed separate two-factor group (keyboard, no music) \times time (pretest, 4 months, 8 months) mixed analyses of variance (ANOVAs) with time as the repeated measure on each task. The outcome of this analysis is reported in Table 3. The ANOVA performed on the Puzzle Solving task showed significant main effects for both group and time and a significant interaction between group and time. Similar effects were found for the Block Building task. The ANOVA performed on Pictorial Memory yielded a main effect for time only and an interaction between group and time. Because we were unable to randomly assign children to groups, we next performed a two-factor (sex, group) MANOVA on the pretest scores for the Puzzle Solving, Block Building, and Pictorial Memory tasks to be absolutely certain that the children's scores prior to treatment were equiv-

Table 3. Two-Factor (Group, Time) Analyses of Variance for Puzzle Solving, Block Building and Pictorial Memory Tasks

Source	df	F		
		Puzzle Solving	Block Building	Memory
Group (G)	1	11.63*	7.13*	1.28
Time (T)	2	61.45**	17.16**	24.53**
G × T	2	10.55**	4.71*	8.3**
S within-group error	120	(7.51)	(1190.07)	(0.76)

Notes: Values enclosed in parentheses represent mean square errors.

S = subjects.

* $p \leq .001$; ** $p < .0001$.

alent across group and sex. No significant main effects for group ($\eta^2_{(3,56)} = 0.01$, $p > .05$) or sex ($\eta^2_{(3,56)} = 0.01$, $p > .05$) were found, nor was there a significant interaction between group and sex ($\eta^2_{(3,56)} = 0.05$, $p > .05$).

Scheffe t tests further revealed that the pretest scores of the keyboard and no music groups did not differ significantly for any variable (Puzzle Solving: $t = 0.15$, $p > .05$; Block Building: $t = 0.198$, $p > .05$; Pictorial Memory: $t = 0.143$, $p > .05$). However, the children in the keyboard group scored significantly higher on the Puzzle Solving and Block Building tasks after 4 months of lessons than did the children in the no music group (Puzzle Solving: $t = 4.90$, $p \leq .05$; Block Building: $t = 5.99$, $p \leq .001$). After 8 months of lessons the difference in spatial-temporal task scores between the keyboard and no music groups had further increased (Puzzle Solving: $t = 10.9$, $p \leq .001$; Block Building: $t = 4.7$, $p \leq .001$). No significant differences between groups were found for the Pictorial Memory task (4 months: $t = 3.74$, N.S.; 8 months: $t = 1.37$, N.S.).

An additional method for assessing learning over time is to calculate and analyze gain scores (posttest minus pretest). This method, however, fails to control for the common observation that children who score the lowest on cognitive pretests tend to improve the most over time (Bereiter, 1963; Linn & Slinde, 1977), in which case their posttest scores are somewhat dependent on their pretest scores. We, therefore, used a covariance approach to factor out the pretest scores' effect on the outcome measures. Using posttest scores as an outcome measure with the pretest scores as a predictor, we performed a one-factor (group) multivariate analysis of covariance (MANCOVA) by using pretest scores as the covariate and gain scores (8 months - pretest, presented in Table 4) as the dependent measure. This analysis yielded a significant main effect for group ($\eta^2_{(3,53)} = 0.35$, $p < .001$), indicating that the effect for group revealed by the MANOVA performed earlier was not an artifact of the children's pretest scores. The MANCOVA also revealed that the effect for sex ($\eta^2_{(3,56)} = 0.04$, $p > .05$) and the interaction between group and sex ($\eta^2_{(3,56)} = 0.02$, $p > .05$) were not significant.

Table 4. Mean Gain Scores (Pretest – 8 Months) for Keyboard ($n = 34$) and No Music ($n = 28$) Groups

Group	Task					
	Puzzle Solving ^a		Block Building ^b		Pictorial Memory ^a	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Keyboard	7.43	4.94	-49.97	51.17	1.5	1.46
No Music	2.94	3.05	-18.95	52.44	.57	1.29

Notes: ^a The higher the score is, the greater the improvement.

^b The lower the score is, the greater the improvement.

DISCUSSION

The primary contribution of this study was to demonstrate the effects of music instruction on the spatial-temporal reasoning of kindergarten children in the chaotic setting of the public school classroom. The results revealed that the children exposed to keyboard lessons improved significantly on the two spatial-temporal tasks administered, regardless of group instruction and a hectic classroom environment. The enhancements found in this study were similar in magnitude to those found in similar studies (Rauscher et al., 1994, 1997), despite vast differences in the setting in which the instruction occurred and the participation of older children. Although no differences in pretest scores were found between the keyboard and no music groups, the keyboard group scored significantly higher than the no music group after only 4 months of lessons, a difference that was greater in magnitude after 8 months of lessons. As predicted, pictorial memory did not differ for the two groups following lessons.

Although the Pictorial Memory task did not improve as a function of music instruction, the MANOVA revealed a significant interaction between group and time for this variable. This interaction was caused by a slight (insignificant) decrease in the no music group's scores after 4 months of instruction, followed by a significant increase after 8 months, as predicted. Although the keyboard and no music groups did not differ for any testing period, the nonlinear pattern of results for the no music group produced the interaction. Because the dip in scores for the no music group was not significant ($t = 1.55, p > .05$), it is unlikely that this interaction suggests a meaningful trend.

These data support Leng and Shaw's (1991) hypothesis that early music training enhances spatial-temporal reasoning and are consistent with studies that found improved spatial-temporal task scores in preschoolers after music instruction (Gromko & Poorman, 1998; Mallory & Philbrick, 1995; Rauscher et al., 1994, 1997). Costa-Giomi's (1999) findings were also supported. However, unlike previous studies the children in the present study were provided with the lessons in groups of 10 rather than individually. It seems that private lessons are not needed to induce the enhancement, an important financial consideration for researchers planning further studies in this area.

Although these findings would be strengthened by the inclusion of a control

group receiving lessons in something other than music, we suggest that the between-group uniformity of Pictorial Memory scores (see Table 2) minimizes the presence of a Hawthorne effect for the spatial-temporal tasks. Furthermore, Rauscher et al. (1994, 1997) found no differences between effects observed in prior studies conducted both with and without the inclusion of an additional control. Nevertheless, further work is needed to eliminate this alternative explanation.

Deriving implications for practice from these experimental data has its pitfalls because this study was designed with an eye towards determining the parameters of a scientific effect rather than with an eye towards application. The picture portrayed by these data are of children who score significantly higher on mathematically relevant tasks after only 4 months of classroom keyboard lessons, a trend that increased over time. This finding has strong implications for educators. However, several pedagogical questions remain unanswered.

First, the optimal age to begin the training is unknown. Whereas effects have been demonstrated for both preschoolers and 9-year-olds, no studies have determined differences in effect size for these age groups. Although we expect to find the enhancement throughout early childhood, younger children's (≤ 3 years) cortical plasticity (Rakic, 1997) may induce the largest effects. A cross-sectional study in which children are administered the same tasks would help resolve this.

Second, little is known regarding the duration of the enhancement. Although studies have found that the effect lasts at least 1 day (Rauscher et al., 1997), curricular applications can only be derived if persistent effects are demonstrated. Rauscher, Robinson, and Jens (1998) found that early music exposure can induce long-term improved spatial performance in rats. If this improvement was precipitated by anatomical alterations in the brain's spatial processing sites, as recent pilot data suggest (Rauscher & Koch, 1999), it is possible that the effects reported for the children are also neuroanatomically induced. Longitudinal studies are needed to determine whether the behavioral effects found for children are lasting, as were those found for the rats. It is also important to learn if the enhancement remains after termination of the lessons. Gardiner et al. (1996) found that the number of years of music and arts training was positively correlated with math achievement. Perhaps extensive instruction is required for optimal effects on brain development and learning.

Third, little is known regarding the contributions of either the curriculum or musical instrument. Previous studies have explored the effect of keyboard lessons or songbells on spatial-temporal reasoning (Costa-Giomi, 1999; Gromko & Poorman, 1998; Mallory & Philbrick, 1995; Rauscher et al., 1994, 1999). The keyboard confers a linear relationship of the spatial distances between the pitches aurally, visually, and motorically (Rauscher et al., 1997). Perhaps any instrument (e.g., xylophone, songbells) providing spatial information across modalities is suitable. A child playing (for example) a cello, tuned in fifths, is not privy to this type of linear feedback. Alternatively, it is possible that training in music, regardless of the medium, is the catalyst. Indeed, unlike previous studies the curriculum used in the present study incorporated several components of musical instruction along with the keyboard training, including singing, movement, ear

training, music literacy, and solfege. Moving to music involves, among other things, the integration of kinesthetic and aural abilities. Learning to read music involves symbolic reasoning and planning skills. It may be that proficiency in some or all of these musical activities is integral to improved spatial-temporal task performance. A limitation of the current study's design is that it did not address the relative contributions of individual musical activities, making it impossible to attribute the enhancements to any one aspect of the curriculum, including keyboard instruction. Studies exploring the effect by isolating the various components of music instruction are clearly needed.

Finally, although significant correlations have been found between spatial-temporal task performance and mathematical ability (Gordon, 1997), studies are needed to determine whether music affects mathematical reasoning as it affects spatial-temporal reasoning, as Gardiner's (1996) study suggests. A study by Shaw et al. (Graziano, Peterson, & Shaw, 1999) addressed this hypothesis. The researchers compared the proportional reasoning abilities of second-grade children assigned to four groups: (1) keyboard instruction coupled with exposure to a computer game designed to develop spatial-temporal reasoning; (2) English instruction coupled with the same spatial-temporal training; (3) spatial-temporal training only; (4) no treatment. Results indicated that the proportional reasoning scores of the children whose treatment included the music instruction was significantly higher than that of the children in the other groups. This suggests that music instruction may enhance proportional reasoning relating to certain mathematical abilities, such as understanding fractions and ratios, and confirms the role of spatial-temporal reasoning in some mathematical operations (Gordon, 1997).

By demonstrating music-induced enhancement of spatial-temporal task performance in two public elementary schools, this study greatly broadens the range of potential application. Whereas prior studies using the keyboard have demonstrated enhancements through private instruction (Costa-Giomi, 1999; Rauscher et al., 1994, 1997), this research showed that enhancements are achievable through class instruction, strengthening the case for the inclusion of music in the classroom curriculum. The impact of the music instruction was immediate, beginning after only 4 months of instruction and increasing with the duration of instruction. Although there are several hypotheses remaining for investigation, the effects found in this study were large enough and persistent enough to encourage further work on the relationship between music education and cognitive development. We urge the commencement of "educational trials," as recommended by Weinberger (1998), to "bring theory, from academia, and practice, in the front lines of the schools, together in an equal partnership on a large scale" (p. 34). Care must be taken, however, to ensure that scientific goals do not displace developmentally appropriate instruction. Consistent with recent recommendations of the National Association for the Education of Young Children (Bredekamp & Copple, 1997), a position statement containing guidelines for the establishment of age-appropriate music curriculum has been published by the Music Educator's National Conference ([MENC], 1994). MENC recommended a focus on singing, listening, movement, instrumental instruction, creativity, and music literacy as well as the development of musical knowledge of melody, rhythm, timbre, and form. Musical

play is also highly recommended, as is the encouragement of individual creativity. Kenney (1997) outlined specific teaching strategies relevant to these instructional goals for newborns to children age 8. We encourage scientists and educators to attend carefully to these guidelines when considering the application of these research findings.

Although we feel this research is an important step toward understanding the extramusical benefits of music instruction in public school settings, further systematic research is needed to investigate how music education relates to other academic areas. For many children, particularly the disadvantaged, the quality of an elementary public school education can mean the difference between success and failure in life. We suggest that research exploring the effects of music instruction on cognitive development can contribute to the academic and social welfare of these children.

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NOTES

1. Information on curriculum is available from Mary Anne Zupan at Wales Elementary, 219 Oak Crest Drive, P.O. Box 130, Wales, WI 53183.
2. Pretesting was conducted solely by Mary Anne Zupan; the 4-month testing session was conducted by Mary Anne Zupan aided by a colleague; the 8-month testing session was conducted by the colleague alone.
3. Please note that the Puzzle Solving and Block Building tasks are reverse scored, resulting in negative correlations.

REFERENCES

- Arnheim, R. (1969). *Visual thinking*. Berkeley: University of California Press.
- Barlow, H. B. (1961). Possible principles underlying the transformation of sensory messages. In S. W. Rosenblith (Ed.), *Sensory Communication* (pp. 217–234). Cambridge, MA: MIT Press.
- Barret, H., & Barker, H. (1973). Cognitive pattern perception and musical performance. *Perceptual and Motor Skills*, 36, 1187–1193.
- Bereiter, C. (1963). Some persisting dilemmas in the measurement of change. In C. W. Harris (Ed.), *Problems in measuring change* (pp. 35–52). Madison, WI: University of Wisconsin Press.
- Biederman, I. (1987). Recognition by components: A theory of human image understanding. *Psychological Review*, 94, 115–147.
- Bredenkamp, S., & Copple, C. (Eds.). (1997). *Developmentally appropriate practice in early childhood programs: Revised edition*. Washington, DC: National Association for the Education of Young Children.
- Costa-Giomi, E. (1999). The effects of three years of piano instruction on children's cognitive development. *Journal of Research in Music Education*, 47(5), 198–212.
- Elliot, J. (1980). Classification of figural spatial tests. *Perceptual and Motor Skills*, 51, 847–851.
- Elliot, J., & Smith, I. M. (1983). *An international directory of spatial tests*. Windsor, UK: NFER-Nelson.

- Gardiner, M. F., Fox, A., Knowles, F., & Jeffrey, D. (1996). Learning improved by arts training. *Nature*, 381, 254.
- Gardner, H. (1983). *Frames of mind*. New York: Basic Books.
- Gardner, H. (1993). *Multiple intelligences: The theory in practice*. New York: Basic Books.
- Gardner, H. (1997). Is musical intelligence special? In V. Brummett (Ed.), *Ithaca Conference '96: Music as Intelligence* (pp. 1–12). Ithaca, New York: Ithaca College Press.
- Gordon, L. (1997). *Relationships between spatial reasoning and mathematical ability*. Unpublished manuscript.
- Graziano, A., 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 preschooler's spatial-temporal task performance. *Journal of Research in Music Education*, 46, 173–181.
- Halpern, D. F. (1992). *Sex differences in cognitive abilities* (2nd ed.). Hillsdale, NJ: Erlbaum.
- Hassler, M., Birbaumer, N., & Feil, A. (1985). Musical talent and visual-spatial abilities: A longitudinal study. *Psychology of Music*, 13, 99–113.
- Hebb, D. O. (1949). *The organization of behavior*. New York: Wiley.
- Hughes, J. R., Daaboul, Y., Fino, J. J., & Shaw, G. L. (1998). The "Mozart Effect" on epileptiform activity. *Clinical Electroencephalography*, 29, 109–119.
- Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Cambridge University Press.
- Kalmár, M. (1982). The effects of music education based on Kodaly's directives in nursery school children—from a psychologist's point of view. *Psychology of Music Special Issue* (pp 63–68).
- Kenney, S. H. (1997). Music in the developmentally appropriate integrated curriculum. In C. H. Hart, D.C. Burts, & R. Charlesworth (Eds.), *Integrated curriculum and developmentally appropriate practice* (pp 103–144). Albany, NY: SUNY Press.
- Kritchevsky, M. (1988). The elementary spatial functions of the brain. In J. Stiles-Davis, M. Kritchevsky, & U. Bellugi (Eds.), *Spatial Cognition: Brain Bases and Development* (pp. 111–140). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Krumhansl, C. L. & Jusczyk, P. W. (1990). Infants' perception of phrase structure in music. *Psychological Science*, 1, 70–73.
- Learning Accomplishment Profile Standardized Assessment*. (1992). Louisville, NC: Kaplan Press.
- 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.
- Linn, M. C., & Peterson, A. C. (1985). Emergence and characterization of sex differences in spatial ability. *Child Development*, 56, 1479–1498.
- Linn, R. L., & Slinde, J. A. (1977). The determination of the significance of change between pre- and posttesting periods. *Review of Educational Research*, 47, 121–150.
- Mallory, M. E., & Philbrick, K. E. (1995, June). *Music training and spatial skills in children*. Paper presented at the meeting of the American Psychological Society, New York.
- Manturzewska, M. (1978). Psychology in the music school. *Psychology of Music*, 6, 36–47.
- McCarthy, D. (1972). *McCarthy scales of children's abilities*. San Antonio, TX: The Psychological Corporation.
- McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin*, 86, 889–918.
- Music Educators National Conference. (1994). *The school music program: A new vision*. Music Educators National Conference: Reston, VA.
- Newsome, W. T., Britten, K. H., & Movshon, J. A. (1989). Neuronal correlates of a perceptual decision. *Nature*, 341, 52–53.
- Nicolopoulou, A. (1988). Interrelation of logical and spatial knowledge in preschoolers. In J. Stiles-Davis, M. Kritchevsky, & U. Bellugi (Eds.), *Spatial cognition: Brain bases and development* (pp. 207–230). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Olsho, L. W., Schoon, C., Sakai, R., Turpin, R., & Sperduto, V. (1982). Auditory frequency discrimination in infancy. *Developmental Psychology*, 18, 721–726.
- Papousek, M. (1982, March). *Musical elements in mother-infant dialogues*. Paper presented at the International Conference on Infant Studies, Austin, TX.

- Rakic, P. (1997). Corticogenesis in human and nonhuman primates. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 127–145). Cambridge, MA: MIT Press.
- Rauscher, F. H. (1999). *Enhancing abstract reasoning in disadvantaged children*. Unpublished raw data.
- Rauscher, F. H., & Koch, J. E. (1999). *The effects of exposure to music on spatial processing sites in rats*. Unpublished raw data.
- Rauscher, F. H., Robinson, K. D., & Jens, J. J. (1998). Improved maze learning through early music exposure in rats. *Neurological Research*, 20, 427–432.
- Rauscher, F. H., & Shaw, G. L. (1998). Key components of the Mozart effect. *Perceptual and Motor Skills*, 86, 835–841.
- Rauscher, F. H., Shaw, G. L., Levine, L. J., Ky, K. N., & Wright, E. L. (1994, August). *Music and spatial task performance: A causal relationship*. Paper presented at the meeting of the American Psychological Association, Los Angeles, CA.
- Rauscher, F. H., Shaw, G. L., Levine, L. J., Wright, E. L., Dennis, W.R., & Newcomb, R. L. (1997). Music training causes long-term enhancement of preschool children's spatial-temporal reasoning. *Neurological Research*, 19(1), 1–8.
- Rideout, B. E., & Laubach, C. M. (1996). EEG correlates of enhanced spatial performance following exposure to music. *Perceptual and Motor Skills*, 82, 427–432.
- Rosenzweig, M. R., & Bennett, E. L. (1996). Psychobiology of plasticity: Effects of training and experience on brain and behavior. *Behavioral Brain Research*, 76, 57–65.
- 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(April), 107–116.
- Tunks, T. W. (1992). The transfer of music learning. In R. Colwell (Ed.), *Handbook of research on music teaching and learning* (pp. 437–447). New York: Schirmer Books.
- Weinberger, N. (1998). Brain, behavior, biology, and music: Some research findings and their implications for educational policy. *Arts Education Policy Review*, 99, 28–36.