198 JRME 1999, VOLUME 47, NUMBER 3, 198–212

The relationship between music and cognitive abilities was studied by observing the cognitive development of children provided (n = 63) and not provided (n = 54) with individual piano lessons from fourth to sixth grade. There were no differences in cognitive abilities, musical abilities, motor proficiency, self-esteem, academic achievement, or interest in studying piano between the two groups of children at the beginning of the study. It was found that the treatment affected children's general and spatial cognitive development. The magnitude of such effects (omega squared) was small. Additional analyses showed that although the experimental group obtained higher spatial abilities scores in the Developing Cognitive Abilities Test after 1 and 2 years of instruction than did the control group, the groups did not differ in general or specific cognitive abilities after 3 years of instruction. The treatment did not affect the development of quantitative and verbal cognitive abilities.

Eugenia Costa-Giomi, *McGill University*

The Effects of Three Years of Piano Instruction on Children's Cognitive Development

Experienced musicians and musically talented individuals differ from nonmusicians in the development of specific cognitive abilities and in certain aspects of the brain structure and functioning (Barrett & Barker, 1973; Besson, Faita, & Requin, 1994; Bever & Chiarello, 1974; Hassler, 1992; Hassler, Birbaumer, & Feil, 1985; Hassler & Nieschlag, 1989; Johnson, Petsche, Richter, von Stein, & Filz, 1996; Manturzewska, 1978; Schlaug, Jancke, Hung, & Steinmetz, 1995; Schlaug, Amunts, Janke, & Zilles, 1996). It has been found that, in general, musicians obtain higher scores in tests of spatial abilities

This study was funded by a grant from the National Piano Foundation. Eugenia Costa-Giomi is an associate professor in the Faculty of Music, Strathcona Music Building, McGill University, 555 Sherbrooke Street West, Montreal, Quebec, H3A 1E3, Canada.

than do subjects with no music training (Barret & Barker, 1973; Gromko & Poorman, 1998; Hassler & Nieschlag, 1989; Hassler, 1992; Hurwitz, Wolff, Bortnick, & Kokas, 1975; Karma, 1979; Manturzewska, 1978; Philbrick & Mallory, 1996; Rauscher, Shaw, et al., 1997). Many of these studies' conclusions were based on correlations between spatial and musical abilities or comparisons between musicians and nonmusicians, raising questions about the type of relationship that exists between these abilities. Is the possession of strong spatial abilities a required characteristic for success in music, or does music instruction improve the development of spatial abilities?

Some studies in which a musical treatment was provided as a controlled condition showed an improvement in specific spatial abilities in rats (Rauscher, Robinson, & Jens, 1997) and humans (Gromko & Poorman, 1998; Philbrick & Mallory, 1996; Rauscher, Shaw, & Ky, 1993; 1995; Rauscher, Shaw, Levine, Ky, & Wright, 1994; Rauscher, Shaw, et al., 1997; Rideout, Dougherty, & Wernert, 1998; Rideout & Taylor, 1997). Other studies, however, failed to find such improvements (Newman et al., 1995; Stough, Kerkin, Bates, & Mangan, 1994). In most investigations, the musical intervention ranged from short listening sessions to 7 months of daily music instruction. Invariably, the studies providing music instruction were conducted with young children. The results of most of these studies showed that children participating in music instruction outperformed children not receiving formal music instruction in one of the five scales of the Performance Wechsler Preschool and Primary Scale of Intelligence–Revised (WPPSI–R), namely the Object Assembly Scale (Philbrick & Mallory, 1996; Rauscher et al., 1994; Rauscher, Shaw, et al., 1997). The music treatment did not affect children's scores in the other Performance Scales of the WPPSI–R, such as Geometric Design, Block Design, and Picture Completion. Only Gromko and Poorman (1998) found an effect of music instruction on children's total raw scores in the Performance WPPSI–R. Interestingly, investigators in an earlier study of the effects of 7 months of daily music instruction on first-graders' spatial abilities found that the treatment did not affect children's scores in the Object Assembly Scale of the Wechsler Intelligence Scale for Children (WISC), but improved their scores in the Children's Embedded Figures Test, the Graham Kendall Memory for Designs Test, the Raven Progressive Matrices, and the Block Design subtest of the WISC (Hurwitz et al., 1975).

It is unclear which types of spatial abilities are affected by music instruction, and it is also unknown whether the improvement in spatial abilities is long-lasting. Research has been based on behavioral observations of cognitive changes gathered immediately after the treatment or within a few days of its conclusion, calling into question the long-term effects of music instruction on cognitive development.

In fact, some of the reported changes in cognitive abilities attributed to music treatments lasted no more than 15 minutes (Rauscher et al., 1993). If there is a neurophysiological basis for the behavioral effects of music on cognitive development, one would expect these effects to be permanent. Unfortunately, there are no longitudinal behavioral studies on this problem, and neurological research on the origins of these effect is scarce.

Sarnthein et al. (1997) used coherence analysis of electroencephalograms (EEGs) to study adults who listened to music or text and then completed a spatial task to investigate the neurological basis of the relationship between spatial cognitive development and music exposure. The data from two of the eight subjects participating in the study suggest that listening to music had a positive carryover effect on the mental processes involved in the spatial task by increasing the functional efficacy of certain neural centers. This evidence is tempered by the lack of explanation regarding the improvement in spatial scores of the other subjects, for whom apparently no music carryover effects were noticed. In addition, the effect of task order was not examined; this begs the question as to whether the improved performance in the spatial task was caused by repeated testing or by the musical intervention.

One of the problems of conducting longitudinal studies on the effects of learning music is the selection of comparable experimental and control groups. Subjects who undertake and persist in music instruction might differ from those who never seek to participate or from those who drop out of music lessons. A survey conducted by Duke, Flowers, and Wolfe (1997) in 30 states in the United States to profile students and families who participate in piano instruction showed that most piano students are Caucasian (80%), female (70%), from upper-middle income families (44% reported family incomes greater than $70,000, 39% reported incomes between $40,000 and $70,000, and 18% reported incomes below $40,000), have well-educated parents (80% of mothers and fathers hold at least one college degree), and live at home with both parents (84%). The privileged environment of the typical piano student is striking. In addition to differences in demographic and family characteristics between students who study music and those who do not participate in formal music instruction, other motivational differences might exist between the two groups. It is possible that the interests and perseverance of the students who take instrumental lessons for an extensive period of time reflect other personal differences between the groups. Whether these differences affect the relationship of cognitive development and music instruction is unknown. The present study controlled for some of these differences and explored their possible impact on the development of cognitive abilities in children participating in formal music instruction.

The present longitudinal study focused on the nonmusical effects of piano instruction in children. This article reports the results regarding the effects of 3 years of piano instruction on children's cognitive abilities. The profile of the children participating in the study was quite different from the profile of a typical piano student as described by Duke et al. (1997); the goal was to examine whether music instruction affects the cognitive abilities of children from less-privileged backgrounds.

METHOD

Subjects

During the summer semester of 1994, a letter describing this project was sent to the parents (n = 698) of all fourth-grade children (all were 9 years old) attending the 20 English-language schools of the largest school board (this corresponds to a school district in the United States) in Montreal, Quebec. Parents of 289 children stated interest in the project. Of the parents who did not respond to the letter, 43 were contacted by phone and 74 by mail to confirm that respondents and nonrespondents did not differ in demographic characteristics relevant to the investigation. A total of 117 children (58 girls and 59 boys) participated in the study. Their parents gave informed consent prior to the start of the intervention. These children had never participated in formal music instruction, did not have a piano at home, and their family income was below $40,000 (approximately $30,000 in U.S. dollars) per annum. Sixty-seven children from 11 schools were assigned to the experimental group (the group receiving piano lessons), and 50 children from 12 schools were assigned to the control group (the group not receiving piano lessons). Because of ethical concerns (such as parents and children feeling discriminated for not being provided with piano lessons) and scheduling conflicts, three schools did not have a control group and four schools did not have an experimental group. In the experimental group, 38% of the children lived with a single parent, while 28% did so in the control group. Approximately half the families had one adult with a full-time or part-time job (51% in the experimental group and 54% in the control group). The proportion of families in the experimental and control groups with unemployed parents was 30% and 22%, respectively. Of these families, 97% reported income from welfare subsidies of less than $20,000 (Canadian). Approximately half the children in each group were boys (49% in the experimental and 51% in the control group).

The sample from the school (n = 20) attended by 10 children who dropped out of the piano lessons was not included in the analyses because the preservation of the randomness of the remaining sample was questionable. The 11 children from other schools who discontinued piano instruction during the 3 years of the treatment but completed all required testing were included as part of the experimental group. Possible differences among the children who dropped out of instruction, those who completed 3 years of piano instruction, and those who never participated in formal music instruction were investigated. Additionally, nine children (three from the experimental group and six from the control group) moved to another city during the 3 years of the study and did not complete the required testing. Because the reason for their withdrawal from the project was unrelated to the treatment, no further analyses were performed on the incomplete data of this group of children. If a child missed one of the multiple administrations of a specific test, the child's remaining scores in this test were not analyzed. This procedure was necessary to allow for the repeated-measures statistical analysis performed with the data. A total of 78 children (35 in the control group and 43 in the experimental group) completed all cognitive abilities tests.

Treatment

Each child in the experimental group received, at no cost to the families, 3 years of piano instruction and an acoustic piano. Nine teachers (six female and three male) provided children with individual piano lessons weekly. Lessons were held at the participating schools during lunch recess or after school hours. The lessons were 30 minutes long during the first 2 years, and 45 minutes in length during the third year. Teachers followed a traditional curriculum based on the development of basic techniques and repertoire from simple popular melodies to classical sonatinas.

Testing

Prior to the treatment, children in both the control and experimental groups were administered five standardized tests with adequate reliability levels for the age of the sample: Level E of the Developing Cognitive Abilities Test (DCAT), the tonal and rhythmic audiation subtests of the Musical Aptitude Profile, the fine motor subtests of the Bruininks-Oseretsky Test of Motor Proficiency, the language and mathematics subtests Level 14 of the Canadian Achievement Test 2 (CAT2), and the Coopersmith Self-Esteem Inventories (long form). At the end of the first, second, and third years of instruction, children took the appropriate level of the DCAT (i.e., levels E, F, and G, respectively) and the self-esteem test. At the end of the second and third years, children also took the language and math subtests of the CAT2. Tests were administered to mixed groups of experimental and control subjects in the same order in all schools. The testing sessions were scheduled during the morning and with appropriate breaks within each session. The only individual test was the motor proficiency test. According to the results of independent *t*-tests, there were no differences between the scores of the control and experimental groups in any of the five standardized tests administered prior to the beginning of the treatment.

The piano teachers completed weekly progress reports with the collaboration of the children. These reports provided information about children's attendance to the lessons and their practice routine during the 3 years of instruction.

RESULTS

To study the effect of the music treatment on children's cognitive development, a series of analyses comparing the control and experimental groups were performed. Another set of analyses compared the cognitive development of three groups of children: those who completed the 3 years of treatment, those who never participated in formal music instruction, and those who dropped out of the lessons. This second set of analyses was done to determine whether the differences between the control and experimental groups found in the first series of analyses were the result of a process of attrition during which less-capable children dropped out of the treatment. The third set of analyses added a number of additional independent variables to the model: sex, income, family structure (single- or two-parent family), and parental employment. These variables could not be included simultaneously because of certain redundancy in the information. For example, all families with unemployed parents had incomes of less than $20,000 (Canadian). Finally, certain exploratory analyses, such as regression analyses, were performed.

The total cognitive abilities scores (dependent variable) of the control and experimental groups (between-subjects variable) in 1994, 1995, 1996, and 1997 (i.e., Year, within-subjects variable) were compared through an analysis of variance (ANOVA) with repeated measures. The interaction between Group and Year was significant, $F(3, 228) = 3.90$, adjusted G–G p = .01. Tukey comparisons indicated significant differences in the scores of the control and experimental groups after 2 years of instruction ($p = .05$). There were no differences between the groups prior to the treatment and after 1 and 3 years of instruction (Figure 1).

To determine which types of cognitive abilities were affected by the treatment, three analyses of variance (ANOVAs) with repeated

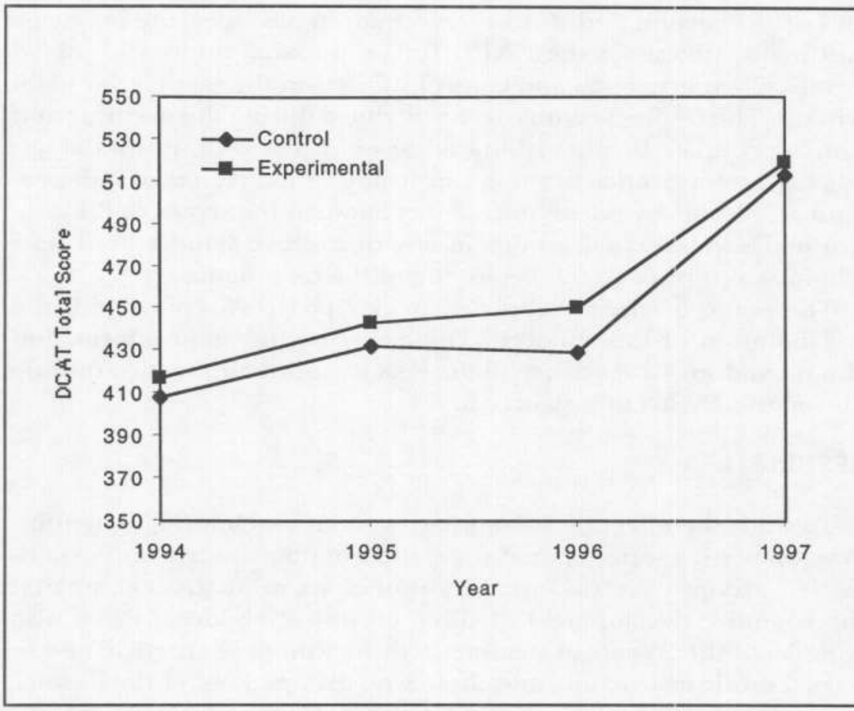

Figure 1. Control and experimental groups' general cognitive abilities scores.

measures were performed on the three subtests of the cognitive abilities test: verbal, quantitative, and spatial. Group (between-subjects variable) and Year (within-subjects variable) were the independent variables, and subtest scores, the dependent variable. A significant interaction between Group and Year was found for the spatial subtest scores, F (3, 228) = 5.28, adj. G-G $p < .01$. Tukey comparisons indicated that the experimental group's spatial scores were higher than those of the control group after 1 and 2 years of instruction (p =.05) and that the groups' spatial scores did not differ prior to the treatment or after 3 years of piano lessons (Figure 2).

The interaction of Group and Year was not significant in the analyses of the quantitative and verbal abilities, suggesting that the musical intervention had no effect on the development of these abilities. The significant effects of the music treatment on general cognitive abilities and spatial abilities were studied in more detail by determining the magnitude of these effects. The omega-squared value, which provides a relative measure of the size of a variable effect, was

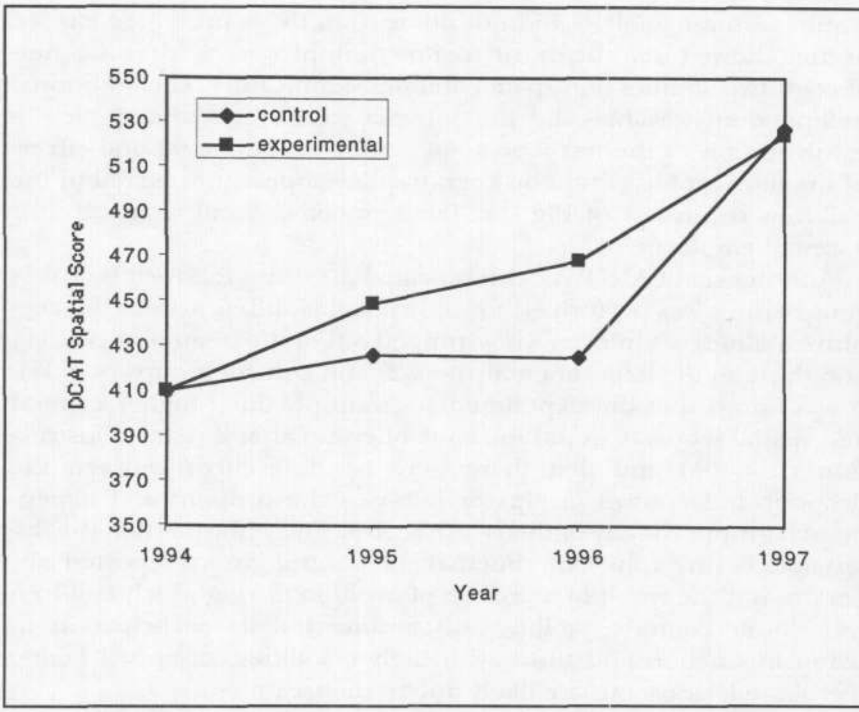

Figure 2. Control and experimental groups' spatial abilities.

used for this purpose. The omega-squared value for the effects of the music treatment on general cognitive abilities was .02, and for those on spatial abilities, .04. According to Keppel (1982), values of less than .06 are considered small in the behavioral and social sciences.

To study possible interactions between relevant demographic characteristics of the sample and the music treatment, the data was reanalyzed to include gender, income (in Canadian dollars, < $20,000; $20,000–$30,000; or $30,000–$40,000), family structure (single- or two-parent family), and parental employment (0, 1, or 2 employed adults in the household) as independent variables. As described earlier, these variables could not be included simultaneously because of certain redundancy in the information. Separate ANOVAs with repeated measures, including Group (between-subjects variable), Year (within-subjects variable), and one additional independent variable (between-subjects variable), were conducted on children's total scores in the DCAT. Similar analyses were also performed on children's spatial, verbal, and quantitative scores from the DCAT. The results of these analyses did not differ from those presented earlier, as they showed that the music treatment improved children's general cognitive abilities and spatial abilities significantly. The additional independent variables did not interact with the treatment significantly for any of the test scores, suggesting that the temporal effects of the music intervention on cognitive development occurred in the children regardless of the sex, family income, family structure, or parental employment.

Another set of ANOVAs with repeated measures followed by Tukey comparisons was performed to study possible differences in the cognitive abilities of children who dropped out of the treatment ($n = 11$) and those in the experimental ($n = 32$) and control groups ($n = 35$). It was found that the experimental group obtained higher general and spatial scores than did the control group after 2 years of instruction ($p = .05$) and that there were no differences between the dropout and control groups or between the dropout and experimental groups for any of the DCAT scores. This indicates that the differences between the experimental and control groups reported earlier are not the result of a process of attrition during which children with lower cognitive abilities discontinued their participation in piano instruction and those with higher abilities continued taking the piano lessons, but are likely due to the treatment.

A question that seemed relevant to consider was whether the effects of piano instruction on cognitive abilities were dependent on children's efforts in learning to play the piano. Because the children in this study did not seek to engage themselves in music instruction but were solicited directly to take piano lessons, they probably came to the study with diverse levels of motivation in learning music. A series of exploratory analyses was performed with the data collected through the weekly piano progress reports of the children in the experimental group. From these reports, it was possible to calculate the number of lessons children missed per year and the average time in minutes they practiced per week. These two types of observations, which reflected children's dedication to learning the piano, were included in multiple regression analyses as the independent variables. The differences between the pretest scores (verbal, quantitative, spatial, and total) and the scores obtained after 1, 2, and 3 years of instruction were calculated for each child in the experimental group and included in the analyses as the dependent variables. To include the partial data from children who had dropped out of the lessons, multiple regression analyses were performed with the cumulative data of children who completed 1 ($n = 61$), 2 ($n = 42$), and 3 ($n = 38$) years of instruction. Significant results were found only for the multiple regression of general cognitive abilities and spatial abilities of the children who completed 3 years of piano lessons, $F\,(2,37)$

= 4.82, $p = .01$, and $F(2,37) = 4.76$, $p = .01$ respectively. Effort to learn the piano, as measured by lessons missed and average practice time per week, explained 21% of the variance in spatial abilities and 22% of the variance in total cognitive abilities after 3 years of piano instruction. No significant results were found in the multiple-regression analyses of children who completed 1 and 2 years of instruction.

DISCUSSION

The results of the study show that the treatment improved children's general cognitive abilities and spatial abilities significantly but that these improvements were only temporary. After 2 years of piano instruction, children in the experimental group obtained significantly higher total scores in the cognitive abilities test than did the children in the control group. The spatial scores of the experimental group were also significantly higher than were those of the control group after 1 and 2 years of individual piano lessons. However, no differences in cognitive abilities were found between the groups after 3 years of instruction, calling into question the long-term effects of the treatment on cognitive development. The same results were obtained when children's sex, family income, family structure (single- or two-parent family), and parental employment were taken into account, suggesting that the temporary effects of the music treatment on cognitive development were not dependent upon these factors. It was also found that individual piano instruction did not affect the development of children's quantitative and verbal cognitive abilities, providing further evidence that the contribution of music instruction to cognitive development might be more limited than has been previously suggested.

Other findings of the study that point to the limitations of the cognitive benefits of the treatment were those regarding the magnitude of the effects (i.e., omega squared). The calculation of the magnitude, which represents the relative size or strength of the treatment effects, yielded values considered low in the behavioral and social sciences (Keppel, 1982). In other words, the temporary improvements in cognitive abilities produced by the treatment, even if significant, were small.

The explanation of these results is difficult because they seem to present conflicting information. On the one hand, the cognitive improvements found after 1 and 2 years of treatment support the idea that music instruction produces neurological changes that in turn improve certain types of cognitive abilities. On the other hand, no cognitive improvements were found after the 3 years of treatment. If it is true that music instruction produces modifications in children's neural processes, one would expect the cognitive improvements to be permanent.

Why did the positive effects of the treatment provided in this study fade after 2 years? I propose that the positive effects of the treatment were dependent upon children's dedication to learning piano. The evidence I have is based on the analysis of the piano progress reports of the children in the experimental group. After 3 years of treatment, 22% of the variance in cognitive improvements of the children receiving piano instruction was explained by their attendance at the lessons and time spent practicing piano. This suggests that children who persisted and participated more actively in the process of learning the piano benefitted to a greater extent than did those less likely to attend the lessons and practice. However, it is important to mention that these factors did not explain the cognitive improvements within the experimental group during the first 2 years of treatment. If these results, which are based on differences within the experimental group, are compared with those reported earlier (based on differences between the experimental and control groups), one will notice an interesting contrast. During the initial 2 years of treatment, differences in cognitive abilities were evident between the control and experimental groups, indicating that the treatment affected children's cognitive development. Additionally, during these 2 years, no effects on cognitive development resulting from dedication to learning the piano were detected within the experimental group. However, after the initial 2 years, no differences in cognitive abilities between the control and experimental groups were found, whereas cognitive development was affected within the experimental group by dedication to learning piano. At the beginning of the project, when children were enthusiastic about the new activity and acquired piano skills faster and more easily, their cognitive abilities improved. After the initial enthusiasm disappeared and progress in learning the piano required more effort and intense involvement, the continuous effect of musical instruction on cognitive development became more dependent upon students' dedication to the task. Perhaps when children start formal music instruction there is an initial improvement in certain cognitive abilities resulting from the new cognitive strategies involved in learning music. However, unless these strategies are further developed through continuous dedication to learning music, the resulting improvements in cognitive abilities might become unnoticeable.

This explanation is in agreement with the results of research comparing the cognitive abilities of musicians and nonmusicians (Barret & Barker, 1973; Hassler et al., 1985; Manturzewska, 1978) and experimental studies conducted with young children (Gromko & Poorman, 1998; Hurwitz et al., 1975; Philbrick & Mallory, 1996, Rauscher, Shaw, et al., 1997). The 6- to 8-month improvement in certain spatial abilities found in children provided with music instruction may have been triggered by the use of newly acquired cognitive strategies, and the superiority of musicians over nonmusicians in certain spatial tests may have been caused by their continuous use of such strategies. At this point, this explanation is speculative because many questions remain unanswered. For example, it is unknown which element of music instruction actually develops these new strategies. In the present study, it could have been the performance of music, the individual attention children received from a caring teacher, the general concentration skills developed during practice, the increased use of symbols that occurred when reading music, or the mere presence of a piano at home. Although traditional piano instruction usually involves all these elements and, as such, contributes to the temporary improvement of certain cognitive abilities, the identification of the exact cause of such improvement could help music educators maximize the beneficial effects of music instruction.

In addition to dedication to learning music, there might be other factors affecting the relationship between music instruction and cognitive development. Hassler and her colleagues (Hassler et al., 1985; Hassler & Nieschlag, 1989; Hassler, 1992), who studied the effects of certain hormones in the development of spatial abilities and creative behavior in music, found that testosterone level is related to artistic talent. This hormone, one of the sex hormones that rises highly during adolescence, was related to the development of spatial abilities in children participating in an 8-year longitudinal study. The relationship between testosterone and spatial abilities was different during their mid-adolescence and late adolescence or adulthood (Hassler, 1992). Interestingly, Hassler found clear differences in spatial abilities between musicians and nonmusicians in adulthood and adolescence, but noticed that these differences were larger during the earlier stages of her longitudinal study than during the later stages. In the present 3-year study, the improvement in spatial abilities was noticed during the first 2 years of treatment when children were between 9 and 12 years old and was not evident after the third year of treatment when children were 12 or 13 years old. It is possible that during the third year of the study, when the children were entering preadolescence, hormonal changes had affected their spatial performance or the relationship between music instruction and their spatial development. The absence of data on the children's hormonal changes makes it impossible to study this idea. Future research conducted with children approaching adolescence might consider including measures of hormonal changes when studying the relationship between music and spatial development.

There is a remarkable consistency in the results of this and previous investigations regarding the temporary effects of music instruction on spatial abilities. The differences in the music treatments, spatial abilities measures, and samples used in the various studies did not seem to affect the main conclusion that music treatment can improve certain spatial skills temporarily. While there are contradictions in the literature regarding the specific types of spatial skills affected by music treatments, there seems to be substantial agreement as to the existence of such effects.

In summary, the results of the study showed that the music treatment produced temporary improvements in children's general cognitive abilities and spatial abilities. The 2-year improvement in general and spatial cognitive scores in children might be of interest to educators searching for ways to help children develop their capabilities. Indeed, a period of 2 years represents a considerable length of time in a child's life. However, because in this study the size of the improvements was small and there were no noticeable effects after 3 years of treatment, music educators should be cautious about setting unrealistic expectations regarding the cognitive benefits of music instruction.

REFERENCES

Barret, H., & Barker, H. (1973). Cognitive pattern perception and musical performance. *Perceptual and Motor Skills, 36,* 1187–1193.

Besson, M., Faita, F., & Requin, J. (1994). Brain waves associated with musical incongruities differ for musicians and non-musicians. *Neuroscience Letters, 168,* 101–105.

Bever, T., & Chiarello, R. (1974). Cerebral dominance in musicians and non-musicians. *Science, 185,* 537–539.

Bruininks-Oseretsky Test of Motor Proficiency. (1978). Circle Pines, MN: American Guidance Center.

Canadian Achievement Tests. (1992). (2nd ed.) Markham, ON: Canadian Test Centre.

Coopersmith Self-Esteem Inventories. (1981). Palo Alto, CA: Consulting Psychologists Press.

Developing Cognitive Abilities Test. (1990). Iowa City, IA: American Testronics.

Duke, B., Flowers, P., & Wolfe, D. (1997). Children who study piano with excellent teachers in the United States. *Bulletin of the Council for Research in Music Education,* no. 132, 51–84.

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.

Hassler, M. (1992). Creative musical behavior and sex hormones: Musical talent and spatial abilities in the two sexes. *Psychoneouroendocrinology, 17* (1), 55–70.

Hassler, M., Birbaumer, N., & Feil, A. (1985). Musical talent and visual-spatial abilities: A longitudinal study. *Psychology of Music, 13,* 99–113.

Hassler, M., & Nieschlag, E. (1989). Masculinity, femininity, and musical composition: Psychological and psychoendocrinological aspects of musical and spatial faculties. *Archives of Psychology, 141,* 71–84.

Hurwitz, I., Wolff, P., Bortnick, B., & Kokas, K. (1975). Nonmusical effects of the Kodaly music curriculum in primary grade children. *Journal of Learning Disabilities, 8* (3), 45–52.

Johnson, J. K., Petsche, H., Richter, P., von Stein, A., & Filz, O. (1996). The dependence of coherence estimates of spontaneous EEG on gender and music training. *Music Perception, 13,* 563–582.

Karma, K. (1979). Musical, spatial and verbal abilities. *Bulletin of the Council for Research in Music Education,* no. 59, 50–53.

Keppel, G. (1982). *Design and analysis: A researcher handbook* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall Inc.

Manturzewska, M. (1978). Psychology in the music school. *Psychology of Music, 6,* 36–47.

Musical Aptitude Profile. (1988). Chicago, IL: Riverside Publishing Company.

Newman, J., Rosenbach, J., Burns, K., Latimer, B., Matocha, H., Rosenthal, E. (1995). An experimental test of "The Mozart Effect": Does listening to his music improve spatial ability? *Perceptual and Motor Skills, 81,* 1379–1387.

Pilbrick, K., & Mallory, M. (1996, April). *Music and the hemispheres: Stimulating brain development through music education.* Paper presented at the meeting of the Music Educators National Conference, Kansas City.

Rauscher, F., Shaw, G., Levine, L., Ky, K., & Wright, E. (1994, August). *Music and spatial task performance: A causal relationship.* Paper presented at the 102nd Annual Convention of the American Psychological Association, Los Angeles, CA.

Rauscher, F., Robinson, K., & Jens, J. (1997). Spatial performance as a function of early music exposure in rats. In A. Gabrielsson (Ed.), *Proceedings of the European Society for the Cognitive Sciences of Music* (pp. 688–692). Uppsala, Sweden: Uppsala University.

Rauscher, R., Shaw, G., & Ky, N. (1993). Music and spatial task performance. Nature, 365, 611.

Rauscher, R., Shaw, G., & Ky, N. (1995). Listening to Mozart enhances spatial-temporal reasoning: Towards a neurophysiological basis. *Neuroscience Letters. 185,* 44.

Rauscher, R., Shaw, G., Levine, L., Wright, E., Dennis, W., & Newcomb, R. (1997). Music training cause long-term enhancement of preschool children's spatial-temporal reasoning. *Neurological Research, 19,* 2.

Rideout, B. E., Dougherty, S., & Wernert, L. (1998). Effect of music on spatial performance: A test of generality. *Perceptual and Motor Skills. 86,* 512–514.

Rideout, B. E, Taylor, J. (1997). Enhanced spatial performance following 10 minutes' exposure to music: A replication. *Perceptual and Motor Skills. 85,* 112–114.

Sarnthein, J., vonStein, A., Rappelsberger, P., Petsche, H., Rauscher, F., & Shaw, G. (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.

Schlaug, G., Jancke, L., Hung, and Steinmetz (1995). In vivo evidence of structural brain asymmetry in musicians. *Science, 267,* 699.

Schlaug, G., Amunts, K., Janke, L., & Zilles, K. (1996). Hand motor covaries with size of motor cortex: evidence for macrostructural adaptation in musicians. In B. Pennycook & E. Costa-Giomi (Eds), *Proceedings of the International Conference on Music Perception and Cognition* (p. 433). Montreal: QC, Canada.

Stough, C., Kerkin, B., Bates, T., & Mangan, G. (1994). Music and spatial IQ. *Personality and Individual Differences, 17,* 695.

Submitted September 20, 1998; accepted May 17, 1999.