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ABSTRACT

This research paper reports on testing the hypothesis that music and spatial task performance are causally related. Two complementary studies are presented that replicate and explore previous findings. One study of college students showed that listening to a Mozart sonata induces subsequent short-term spatial reasoning facilitation and tested the effects of highly repetitive music on spatial reasoning. The second study extends the findings of a preliminary pilot study of 1993 which suggested that music training of three-year-olds provides long-term enhancements of nonverbal cognitive abilities already present at significant levels in infants. The paper concludes with a discussion of the scientific and educational implications, further controls, and future research objectives. Contains 10 references. (EH)

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Music and Spatial Task Performance: A Causal Relationship

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Music and Spatial Task Performance: A Causal Relationship[1]

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Links between music and other forms of human intelligence extend back to the classical discoveries of Pythagoras. But until recently, researchers have demonstrated only correlations between music cognition and spatial reasoning[2] (Hassler, Birbaumer and Feil, 1985; Allman, 1976). A structured neuronal model of the cortex (Leng and Shaw, 1991; Leng, Shaw and Wright, 1990) inspired us to test the hypothesis that music and spatial task performance are *causally* related. This model proposes that musical activity and other higher cognitive functions share inherent neural firing patterns organized in a highly structured spatial-temporal code over large regions of the cortex. Thus, the authors predicted that the music/spatial causal relationship is due to the cultivation of pattern development by groups of neurons brought about by musical operations (Leng and Shaw, 1991).

The above arguments led us to test the following hypothesis: Music, which is universally appreciated from birth, can be used to develop these inherent firing patterns, along with associated behaviors which are relevant to spatial reasoning. Although prior research has shown that listening to music can provide only a short-term spatial facilitation (Rauscher, Shaw and Ky, 1993), we expect that studying music will provide a longer-term facilitation, particularly for very young children in whom the cortex is still maturing.

1 Frances Rauscher is a researcher at the Center for the Neurobiology of Learning and Memory (CNLM); Gordon Shaw is a Professor Emeritus of Physics, and is also a member of the CNLM; Linda Levine is an Assistant Professor at the School of Social Ecology. Requests for reprints should be sent to Frances Rauscher, Center for the Neurobiology of Learning and Memory, University of California, Irvine, CA 92717.

2 Spatial reasoning enables one to perceive the visual world accurately, form and transform mental images of physical objects, and recognize variations of objects (Neisser and Kerr, 1973; Pylyshyn, 1973). It is crucial for such higher brain functions as music, complex mathematics, and chess (Binet, 1966).

We present here data from two complementary studies which replicate and explore previous findings. In earlier work, we demonstrated with college students that listening to a Mozart sonata induces subsequent short-term spatial reasoning facilitation (Rauscher, Shaw and Ky, 1993). The first study presented here replicated these findings, and tested the effects of highly repetitive music (Philip Glass' minimalism and trance-style dance music) on spatial reasoning. We further predicted that short-term memory would not improve after listening to the Mozart sonata. The second study presented here extends the findings of a preliminary pilot study completed in 1993, which suggested that music training of three-year-olds provides long-term enhancements of nonverbal cognitive abilities (Rauscher, Shaw, Levine and Wright, 1993) which are already present at significant levels in infants (Wynn, 1992; Spelke, Breinlinger, Macomber and Jacobson, 1992; Krumhansl, 1990). We conclude with a discussion of the scientific and educational implications, further controls, and future research objectives.

Study 1 - Listening to Music Enhances Spatial Task Performance

Design and Procedure

In a recent study (Rauscher, Shaw and Ky, 1993) thirty-six undergraduates from the Psychology Department of the University of California, Irvine scored 8 to 9 points higher on the spatial IQ reasoning subtest of the Stanford-Binet Intelligence Scale (Thorndike, Hagen and Sattler, 1986) after listening to 10 minutes of Mozart's Sonata for Two Pianos in D Major, K. 448 as compared to taped self-hypnosis instructions or silence. This facilitation lasted only ten to fifteen minutes. Based on these data, we conducted a study to examine the effects of *repeated* exposure to the Mozart Sonata on spatial reasoning, and to determine if highly repetitive music (minimalism and dance) would also enhance spatial task performance. Finally, to find out whether the effects were specific to spatial reasoning or also included memory, we tested the effects of listening to Mozart versus silence on a short-term memory task.

Eighty-four college students were offered $30.00 to participate for five consecutive days. Seventy-nine students completed the experiment, and the scores of those who did not were eliminated from the data set.

In order to divide students into groups with equivalent abilities on the experimental tasks, all students were issued 16 Paper Folding and Cutting items and 16 Memory items on the first day of participation. The Paper Folding and Cutting items, designed to measure spatial reasoning, were derived from the Stanford-Binet Intelligence Scale and were pre-tested to be equally difficult across the five days of participation (Figure 1).

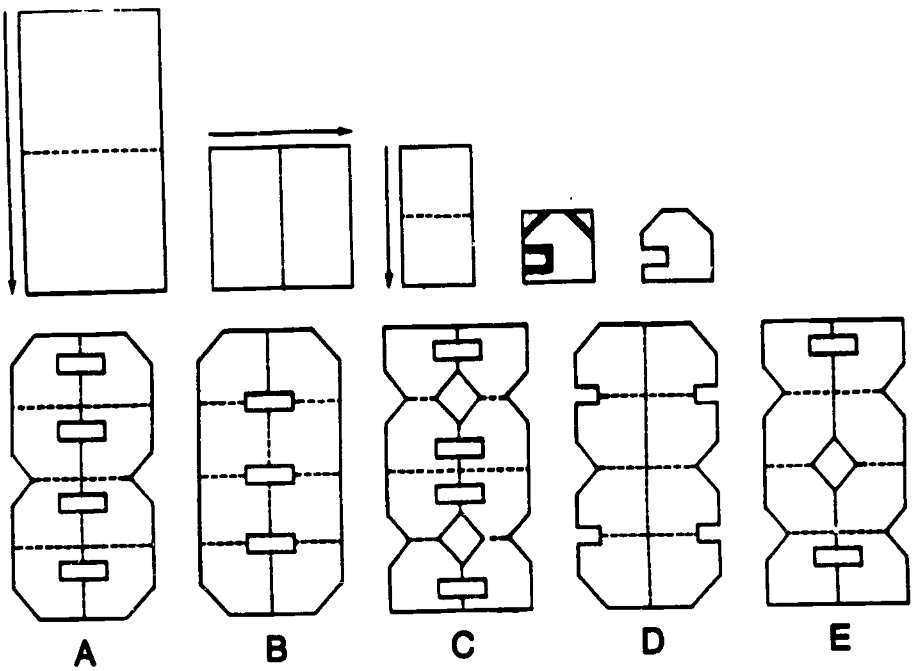

Figure 1. Example of the Paper Folding and Cutting task. Students were presented with a picture of a paper before it was folded and cut (top left figure). The dotted lines and arrows represent where and in what direction the paper would be folded; the solid lines show where the paper would be cut. This paper, for example, would be folded in eighths and then cut in three places. The student was instructed to visualize the folds and cuts and then choose the alternative which shows how the paper would look if it were unfolded.

The items were displayed on an overhead projector for precisely one minute, and the students were warned 5 seconds before the item was removed, to give them sufficient time to choose an answer and to record it in a test booklet. Students were tested in three equal groups. Items were presented one after the other, at a rate of exactly one per minute, as timed by a stopwatch. All three groups of students were issued the same task items. Based on their performance on the Paper Folding and Cutting task, the students were reassigned to one of three groups (silence, mixed and Mozart) of equal means and distributions. These groups participated over the following four days as follows[3].

[3] The three groups were issued the same Paper Folding and Cutting items as each other, which differed day to day.

- Silence (n=26): On days 2-5, an experimenter instructed the students to sit quietly for ten minutes, and then immediately issued 16 new Paper Folding and Cutting items to test spatial reasoning skills.

- Mozart (n=27): On days 2-5, an experimenter instructed the students to listen to ten minutes of the same passage of Mozart's Sonata for Two Pianos K. 448[4], and then were immediately issued 16 new Paper Folding and Cutting items.

- Mixed (n=26): On days 2-4, the independent variable (listening condition) for this group changed daily (see below). Immediately following each of these listening conditions, the students' spatial reasoning skills were tested using 16 Paper Folding and Cutting items.

The conditions for days 2-5 were as follows:
Day 2 - 10 minutes of an audio-tape of minimalist music.[5]
Day 3 - 10 minutes of an audio-taped spoken story.[6]
Day 4 - 10 minutes of an audio-tape of British-style dance (trance) music.[7]
Day 5 - Two groups of 13 students each were formed with equal means and distributions, based on their scores on the Memory items issued on Day 1. One of the groups was removed to another room, and was asked to listen to 10 minutes of the same passage of Mozart's Sonata for Two Pianos K. 448; the other group was instructed to sit in silence for ten minutes. Immediately afterwards, both groups were issued 16 new Memory items (Figure 2).

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[4] This is the same selection of music used in Rauscher, Shaw and Ky's (1993) study.
[5] Philip Glass' Music With Changing Parts.
[6] Melissa Bank's The Chief. This condition was included to determine if the effect was in fact due to music, rather than to attended speech sounds.
[7] Ian Rich's C-Level Productions mix of Mortal Stomp and Carry me Through.

M 9 ! B 2 ~ N

Figure 2. Example of the Memory task. Students were presented with a random array of six–eight letters, numbers and symbols which could not easily be memorized using a rhythmic pattern. Items were presented for five seconds, and the students' task was to write down what they remembered in the correct order. No partial credit was given.

Results

Our measure of spatial reasoning skill was the mean number of Paper Folding items that the subjects answered correctly. We present the data for the silence and Mozart groups first, followed by that for the mixed group, the memory data, and some further analyses.

Silence vs. Mozart Groups

The mean number of Paper Folding items correctly answered by the silence and Mozart groups are graphed for all five days in Figure 3.

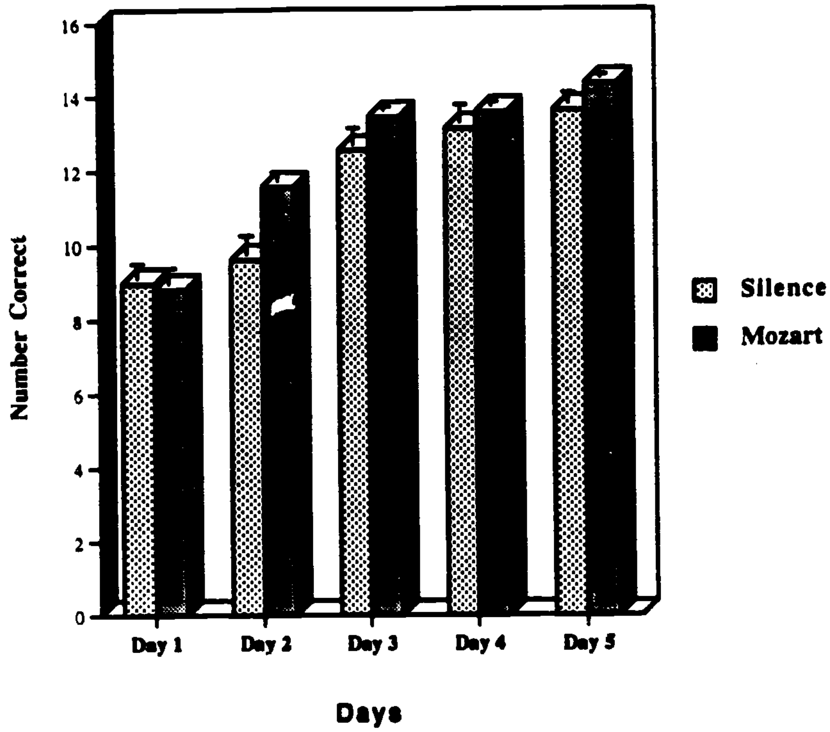


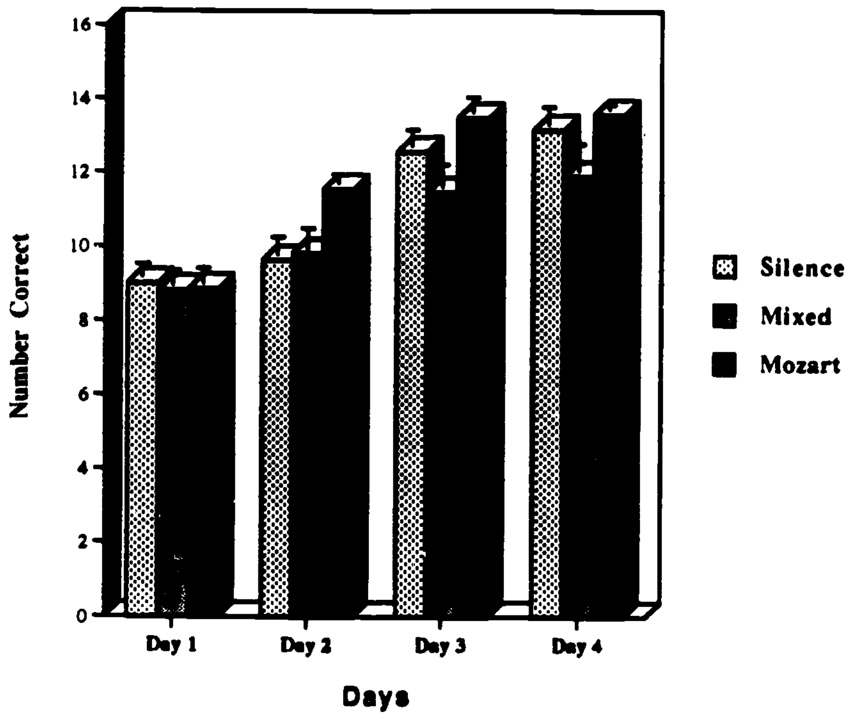
Figure 3. Mean number of Paper Folding and Cutting items answered correctly out of 16 by silence and Mozart groups for Days 1–5.

Our first objective was to determine if these results replicated the Rauscher, Shaw and Ky (1993) finding of significant improvement in spatial reasoning ability after merely one exposure to the Mozart Sonata, and no improvement after silence. To that end, we performed a two (listening condition: silence and Mozart only) by two (day 1: no exposure, and day 2: first exposure to silence or Mozart) analysis of variance (ANOVA). This analysis revealed a significant main effect for day ($F_{(1,51)} = 28.211$, $p < .001$) and a significant interaction between listening condition and day ($F_{(1,51)} = 11.17$, $p < .01$). The Mozart group's scores improved after exposure to the sonata (on day 2), whereas the silence group's scores showed no improvement (Scheffé's $t = 8.13$, $p < .001$ and $t = 1.15$, ns, respectively). As shown by Rauscher, Shaw and Ky (1993), spatial reasoning ability improved after just one encounter with the Mozart sonata.

We next subjected the means for the silence and Mozart groups to a two (listening condition) by five (day) ANOVA to determine if the spatial reasoning enhancement procured by listening to Mozart continued over the five days. We again found a highly significant main effect for day ($F_{(4,204)} = 90.42$, $p < .001$) as well as a significant interaction between listening condition and day ($F_{(4,204)} = 2.87$, $p < .05$). As discussed above, the spatial skills of subjects who listened to Mozart improved immediately from day 1 to day 2 and continued to improve significantly through day 3 ($t = 5.86$, $p < .03$). The silence group's scores did not improve between day 1 and day 2, but did increase significantly between days 2 and 3 ($t = 6.50$, $p < .001$). The scores of the silence and Mozart groups did not differ from each other on days 3, 4 and 5. We speculate that the immediate improvement of the Mozart group's scores (between days 1 and 2) was due to listening to the music, whereas the improvement of the silence group's scores (between days 2 and 3) was the outcome of a learning curve, which we underestimated. We suspect that including more difficult items in future studies will retard this learning curve, and will also permit us to determine if the Mozart group's scores continue to improve significantly over all five days of the experiment. We suspect that this possible outcome was obscured by the ceiling effect shown by the Mozart and silence groups.

Mixed Group

Figure 4 presents the data for the mixed group on days 1 through 4 along with the silence and Mozart groups. A three (listening condition) by four (day) ANOVA again revealed a significant main effect for day ($F_{(3,228)} = 97.48$, $p < .01$) and a significant interaction between listening condition and day ($F_{(6,228)} = 3.16$, $p < .01$).



Mixed Group was assigned as follows:

Day 1: Baseline measures taken
Day 2: Music of Philip Glass
Day 3: Tape-recorded story
Day 4: Dance music

Figure 4. Mean number of Paper Folding and Cutting items answered correctly out of 16 by silence, mixed and Mozart groups for Days 1–4.

These effects, however, are due almost entirely to the silence and Mozart groups. Scheffé t-tests indicated no significant improvement whatsoever for the mixed group. Regardless of what these subjects listened to (minimalist music, story or dance music) their spatial task performance scores stayed at roughly the same level throughout the experiment, showing no significant day-to-day increase or decrease. The marginal improvement seen across the four days for the mixed group is due to the presence of a gradual learning curve, similar to that seen with the silence group.

Effects of Mozart vs. Silence on Short-term Memory

As described above, subjects in the mixed group were further divided into two groups (Mozart and silence) and were issued 16 short-term memory items (refer to Figure 2) on Day 5. We tabulated the number of these items that subjects in the subdivided mixed group answered correctly to ascertain whether performance on a memory task showed the same trend after listening to silence vs. Mozart as did performance on the spatial task. As predicted, the silence ($M = 7.85$) and the Mozart ($M = 7.54$) groups did not differ ($t = 0.18$, ns).

Study 1 Summary

The immediate improvement of the Mozart group's scores on day 2, and the lack of immediate improvement of the silence group's scores, replicates the Rauscher, Shaw and Ky (1993) study. We have also presented data indicating that minimalist or rhythmically repetitive musical structures do not enhance spatial task performance, shown by the lack of improvement of the mixed group's scores after listening to Philip Glass' work or the dance/trance music. It seems that a particular organization of musical elements is necessary for improvement in spatial task performance. Moreover, the audio-taped short story also did not facilitate spatial reasoning, indicating that attention alone is not responsible for the effect. Finally, we have shown that short-term memory does not improve after listening to the Mozart sonata.

It is important to note that the Paper Folding and Cutting task is not simply a spatial recognition task, but rather involves a temporal series of spatial tasks. It is such spatial-temporal pattern development that the model (Leng and Shaw, 1991) predicts will be enhanced through listening to the Mozart sonata. We further predict that the introduction of symmetry operations (such as spatial rotation and/or mirror reflection) into the Paper Folding tasks would produce even larger enhancing effects.

Study 2 - Early Music Training Enhances Spatial Task Performance

Design and Procedure

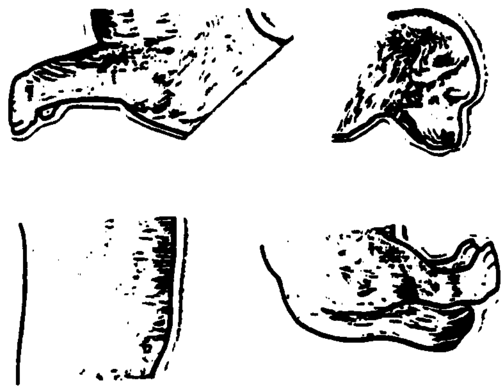
Based on a pilot study showing that ten three-year-old children scored substantially better on a specific spatial reasoning test after receiving music lessons (Rauscher, Shaw, Levine and Wright, 1993) we provided twenty-two preschool children (aged 3 years, 0 months – 4 years, 9 months) enrolled at two Los Angeles County preschools with eight months of keyboard and singing lessons to discern the effects of early music training on spatial abilities. Fifteen children went through the same preschool programs but did not receive any music training. The spatial reasoning scores of the two groups of children were then compared. Thirty-seven children began the study; a total of 33 children participated for the entire eight months (19 in the experimental group, and 14 in the control group).

Music training consisted of weekly 10 – 15-minute private electronic keyboard lessons (taught by two professional piano instructors) and daily 30-minute group singing sessions (led by a professional vocal instructor). All lessons were provided at the preschools. The keyboard lessons involved finger coordination exercises, the association of fingers with numbers, creativity exercises, the association of numbers with musical pitches, musical memory exercises and the introduction of standard musical notation using numbered finger symbols. Children were also given the opportunity to practice their keyboard lesson daily. The practice periods were supervised but not strictly enforced, and most children enjoyed playing the keyboards on a regular basis throughout the week. The children took part in the singing activity together as a group, and each child was encouraged to "lead" the group at least once each week. Songs included popular children's tunes and folk melodies.

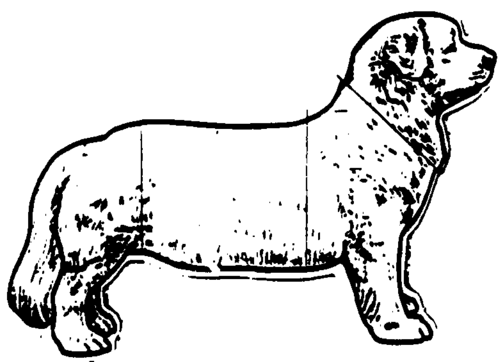
The children's spatial reasoning was tested using five tasks: four from the Performance subtest of the Wechsler Preschool and Primary Scale of Intelligence-Revised (Wechsler, 1989) and one from the Stanford-

Binet Intelligence Scale (Thorndike, Hagen, and Jerome, 1986). The WPPSI-R tasks were: (1) Object Assembly: child arranges pieces of a puzzle to form a meaningful whole (Figures 5a and b); Geometric Design: consists of a visual recognition task and a figure drawing task; (3) Block Design: child matches depicted patterns using flat, two–colored blocks; (4) Animal Pegs: child places correct colored pegs in holes below a series of

(a)



(b)



Figures 5a and b. Example of the Object Assembly task. After placing a shield in front of the child blocking his/her view, the puzzle pieces were arranged according to a specified configuration (a). The shield was then removed, and the child was told that the pieces will "make something", and to put them together as fast as he/she can. The experimenter started a stopwatch as soon as the child's hand touched a piece, and stopped it when the child indicated that the task was completed (shown correctly in (b)).

pictured animals. None of these tasks required a verbal response from the child. The Stanford-Binet task, titled Absurdities, required the child to verbally describe what was "wrong or silly" about a picture presented to him or her, such as a bicycle with square wheels. It was included to determine if the increase in scores found by Rauscher et. al (1993) on the Object Assembly task was due to association with familiar objects.
Raw scores were based on the number of errors the child made within a specified time period, which varied from task-to-task. Bonus points were awarded for accuracy and speed for the Object Assembly, Block Design and Animal Pegs tasks. Scaled scores were calculated ($\underline{M}$ = 10, $\underline{sd}$ = 3) based on several rounds of pilot testing performed by the test developers, who tabulated expected raw scores for children at each three-month age interval.[8]

The Rauscher et al. (1993) pilot study found significant improvement in the children's performance on the Object Assembly task after just the first few months of music training. This improvement continued throughout the nine months of that study. To determine if this effect was replicated, we tested the music group before they began their music lessons, approximately four months after music lessons were initiated, and again about four months later. Every effort was made to ensure that each child had received roughly the same number of keyboard lessons (12 – 14) between testing periods, although due to the frequency of preschool absenteeism this was not always possible. The scores of the children before receiving music lessons were then compared to the scores they achieved at four and eight months after lessons began. Between-test interval data provided by the developers ensured that an increase in test scores was not due to re-testing.

To determine whether the children's improvement on the Object Assembly task was due to some artifact of the task rather than to the music

8 For example, the raw score of a child aged 3 years, 3 months would be expected to be lower than that of a child aged 3 years, 6 months. By preparing a cumulative frequency distribution of raw scores for each age group, normalizing this distribution, and computing an appropriate scaled score for each raw score, the scores of children in differing age groups could be fairly compared.

lessons, the no-music group was tested at four-month intervals as well. If the Object Assembly scores of the no-music group did not improve, we could rule out the likelihood that this task has some unrelated attribute which causes improvement over time.

To sum up, we anticipated three important comparisons: The scores of children who received music lessons with the scores of children who did not; the scores of the music group before their lessons were started and their scores at four and eight months after; and the scores of the no-music group at four-month intervals throughout the duration of the experiment.

Results

Music vs. No-Music Groups

As predicted by the pilot study, the group of children who received eight months of music lessons scored significantly higher on the Object Assembly task than the group of children enrolled in the same preschools who did not receive music training. A two (music vs. no-music group) by five (task) multivariate analysis of variance (MANOVA) revealed a main effect for task ($F_{(4,128)} = 5.26$, $p < .001$).and a condition by task interaction effect ($F_{(4,128)} = 5.83$, $p < .001$). The scaled Object Assembly scores of the 19 children who completed eight months of music lessons were higher than those of the 15 children who did not receive lessons, whereas the two groups' scores on the other four tasks, including Absurdities, did not differ. We next pooled the means of the tasks which did not improve, and performed a two (music vs. no-music group) by two (Object Assembly vs. other tasks) ANOVA. We found significant main effects for group ($F_{(1,32)} = 4.84$, $p < .05$) and for task ($F_{(1,32)} = 13.62$, $p < .001$) and a significant interaction between group and task ($F_{(1,32)} = 27.45$., $p < .001$). These means are graphed in Figure 6.

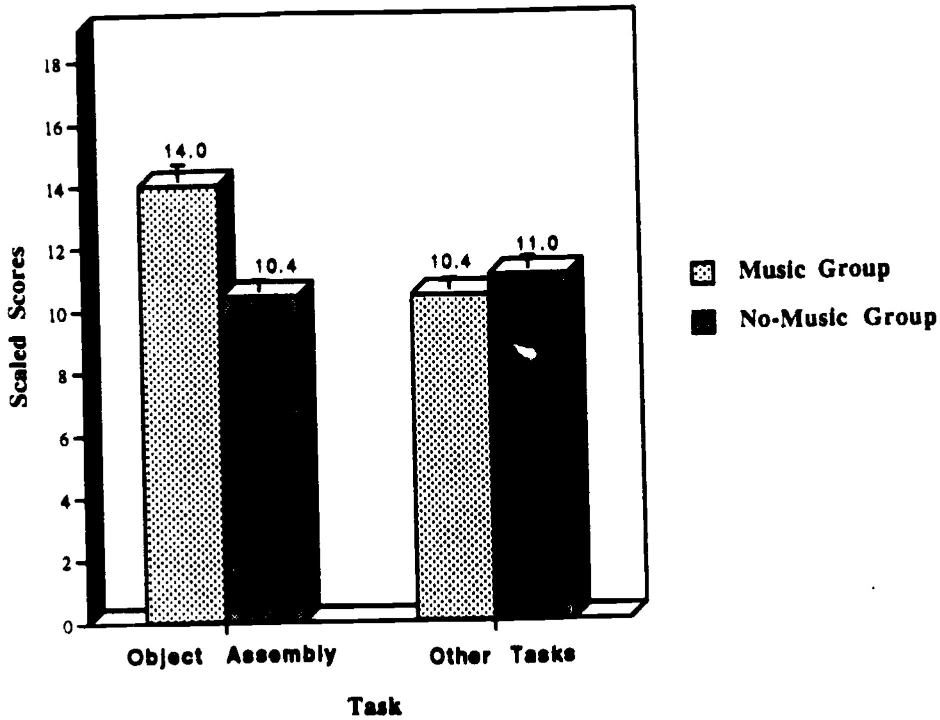


Figure 6. Scaled scores of music and no-music groups on the Object Assembly task versus the other four tasks combined.

Again, the Object Assembly scores of the children who received eight months of music lessons were significantly higher than the scores of the children who did not (14.0 and 10.4, respectively). The combined means for the other four tasks did not differ across the music and no-music groups (10.4 and 11.02, respectively).

Music Group Tested Before vs. After Music Lessons

To determine if the scores of the music group increased after music lessons relative to before, we performed five separate one-factor (testing period) ANOVA's on each of the five tasks. As predicted, the ANOVA for the Object Assembly task yielded a significant main effect for testing period ($\underline{F}(2,36) = 18.76$, $\underline{p} < .001$), indicating that the children's scores dramatically improved after they received music lessons. They scored a mean of 9.6 before beginning their training, 12.8 after four months of lessons ($\underline{t} = 3.98$, $\underline{p} < .001$), and 14.0 after studying music for 8 months ($\underline{t} = 1.39$, ns). Although the 4 – 8-month increase was not statistically significant, the increase in their scores before music lessons were started compared to 8 months after lessons began was dramatic ($\underline{t} = 6.3$, $p < .0001$).

None of the other four task scores showed any significant improvement after music lessons started. In fact, there was very little variance whatsoever for these tasks. Figure 7 compares the means of the Object Assembly task along with the pooled means for the other four tasks before music lessons, four months after lessons were started, and again four months later (eight months after lessons began). The ANOVA performed on the means of these pooled tasks was not significant. ($\underline{F}(2,36) = .57$, ns).

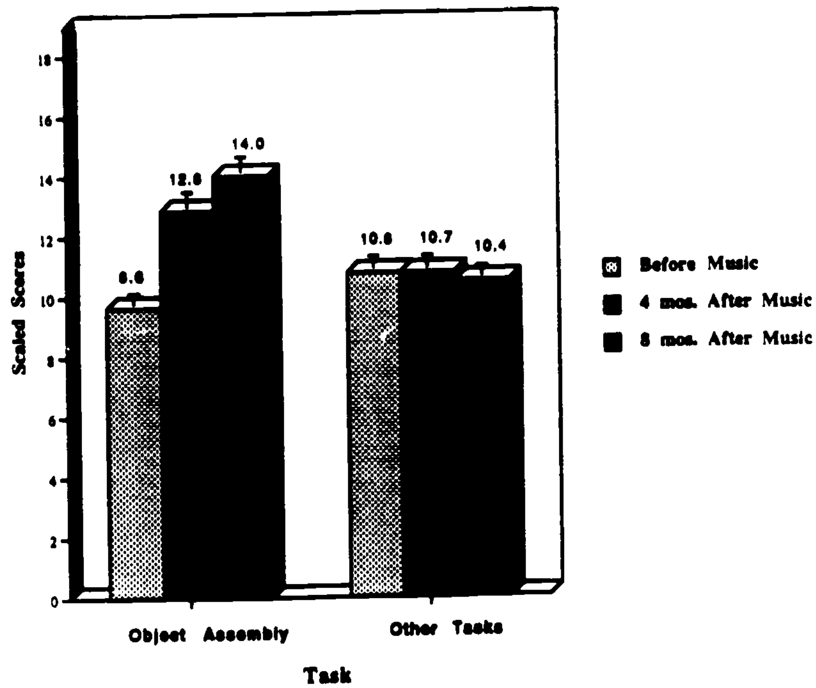


Figure 7. Scaled scores of the music group before music lessons were started, after 4 months of lessons, and after 8 months of lessons for the Object Assembly versus the other four tasks combined.

No-Music Group Tested at Four-Month Intervals

Our final analysis was conducted to determine if the Object Assembly scores (or any scores, for that matter) of the 14 children who participated over the entire eight months of the experiment, but who did not receive music lessons also increased during the four-month testing periods. To that end, we again performed individual one-factor (testing period) ANOVA's on each of the five tasks. We found no significant improvement on any of the five tasks, including the Object Assembly task (($F_{(2,26)} = .36$, ns). This suggests that the increase we found for the music group was most likely due to our independent variable, music lessons, as opposed to an experimental artifact. Figure 8 compares these results with those of the music group.

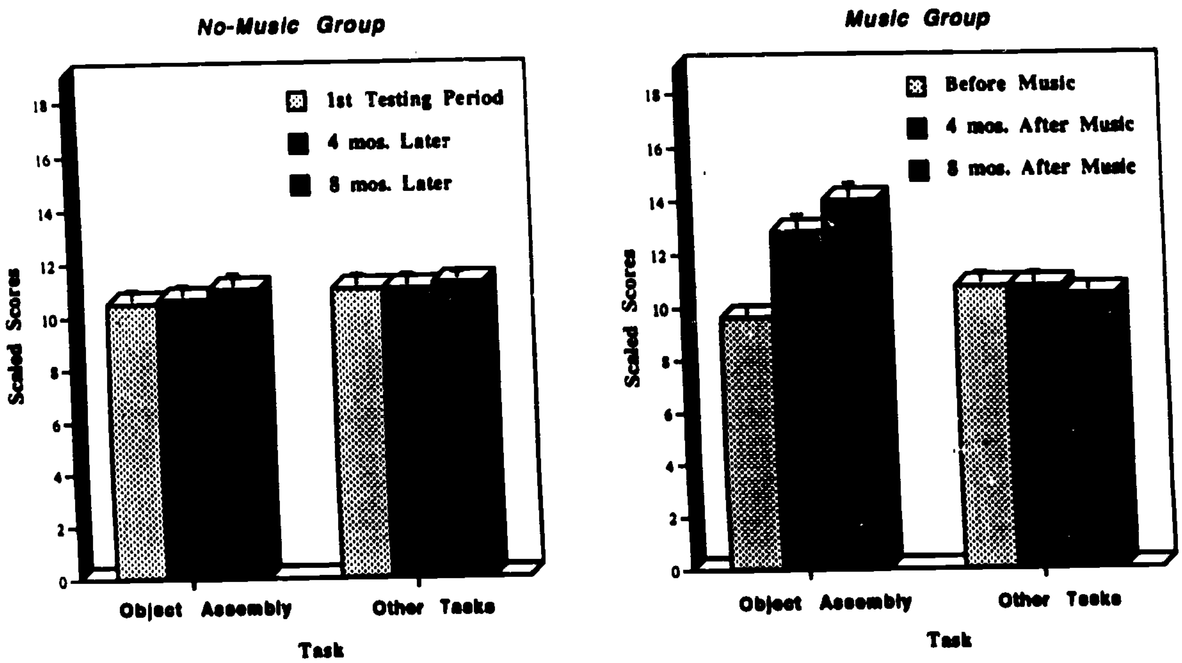


Figure 8. Scaled scores of no-music and music groups across the three testing periods for the Object Assembly tasks versus the other four tasks combined.

Study 2 Summary

The music group's scaled scores on the Object Assembly task were significantly higher after music lessons than those of the no-music control group. Moreover, the music group's scores on this task improved significantly after merely four months of music lessons—findings which replicate the results of our preliminary pilot study (Rauscher et al., 1993). The Object Assembly scaled scores of the children who did not receive lessons remained essentially the same over the eight months of the experiment. As predicted, the scores for tasks other than Object Assembly again failed to increase after music training, suggesting that the improvement was not an artifact of the focused attention given to the Music group. Future studies will provide a group of preschoolers with one-on-one training in a different discipline (such as computers) to further control for this alternative explanation.

The unique qualities of the Object Assembly task elucidate why it improved after music lessons, while the other four tasks did not. The Object Assembly task was the only task given which required the child to form a mental image, and then orient physical objects to reproduce that image. The child had to transform mental images in the absence of complete physical models to guide him or her. In contrast, each of the other four tasks provided the child with a solid object or drawing to match or copy. We propose that success on the Object Assembly task is directed by cortical pattern development facilitated by the music lessons. As with musical performance, task performance requires forming an ideal mental representation of something which is eventually realized. Other tasks which depend upon these spatial/temporal processes should also be regulated by pattern development by related groups of neurons, and should also be enhanced by music training.

Conclusions and Future Directions

These two studies have replicated, extended and explored the facilitating effect of music on spatial task performance suggested in earlier experiments (Rauscher, Shaw Levine and Wright, 1993; Rauscher, Shaw and Ky, 1993). While these findings are compelling, many questions remain unanswered. Future preschool studies will include additional controls, different methods of instruction, and different tests of spatial reasoning. If we can optimize the effect, we hope to investigate ways to integrate music training with standard higher cognitive training in public schools. Although we have shown that music training can improve the spatial reasoning of three-year-olds, further research is needed before we can state with confidence that the effect will be shown with older children, predict how long it will last, or specify a mechanism for it.

We also intend to conduct further research on the Mozart effect. Although there are several different styles of music to investigate, we do not now intend to fully explore a large number of styles and composers. Instead, we are designing tests which we hope will help determine the mechanism that is the source of the enhancement. These further tests will include operations of rotation and mirror reflection. We predict that the enhancement will be even stronger for tests which incorporate these symmetry operations (McGrann, Shaw, Shenoy, Leng and Mathews, 1994). We also intend to develop more difficult tasks of this sort to test master chess players and research mathematicians. In so doing, we hope to demonstrate a positive correlation between the cognitive operations which are involved in math and chess reasoning and those involved in our modified spatial tasks.

The neurophysiological model which inspired these studies (Leng and Shaw, 1991) provides insight into a possible explanation for the results. The model proposes that the inherent firing patterns which result from the columnar structure of the cortex (Mountcastle, 1978) can be enhanced by small changes in connection strengths via a Hebb (1949) learning rule (Shaw, Silverman and Pearson, 1985). These firing patterns are related through specific symmetries, and sequentially evolve from one to another, forming the internal neural language of the cortex.

One way to explore the evolutions of symmetry patterns is to visually diagram them Another way to examine them is to represent them aurally, by mapping pitch and timbre onto the evolutions. When Leng and Shaw(1991) did this, they perceived striking similarities between the tonal output of the model and a variety of compositional styles (i.e., Baroque, New Age, Eastern). These observations led to their prediction that music may be a useful tool for the understanding of higher brain function, followed by their proposition that music can access these inherent brain patterns, enhance the ability of the cortex to do pattern development, and thereby improve other related higher cognitive functions. Musical activities help systematize the cortical firing patterns so they can be maintained for other pattern development duties, in particular, the right hemisphere function of spatial task performance.

To explore the neurophysiological basis of this prediction, we have planned collaborative studies of EEG output. Petsche, Richter, Etlinger and Filz (1994) have shown large differences in EEG coherence patterns when subjects listen to different composers (specifically, Mozart versus Schönberg). We intend to examine EEG coherence patterns of subjects listening to the Mozart sonata (K 448) versus the other musical works which did not enhance spatial task performance (Glass and dance). We will also analyze the patterns of these subjects while they are doing the Paper Folding and Cutting task. We can then compare the patterns generated by listening to the music to those generated during performance of the spatial task. If we can predict the specific musical works which enhance abstract reasoning, we will be closer to our goal of understanding the neurophysiological basis for these data.

We believe that these studies, and future work inspired by them, have the potential to revitalize the role of music in public education. We have shown that music education may be a valuable tool for the enhancement of preschool children's intellectual development. The challenge is to articulate a successful program for music in education that can become a permanent feature of the public school curriculum. We hope to provide the data which will motivate public school officials to apply our findings to primary school programs.

Acknowledgments

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