# Music training causes long-term enhancement of preschool children's spatial–temporal reasoning

**Frances H. Rauscher, Gordon L. Shaw*, Linda J. Levine**, Eric L. Wright†, Wendy R. Dennis‡ and Robert L. Newcomb#**

*Department of Psychology, University of Wisconsin, Oshkosh, WI, *Center for the Neurobiology of Learning and Memory and Department of Physics, **School of Social Ecology, Department of Psychology and Social Behavior, University of California, Irvine, †Irvine Conservatory of Music, ‡Department of Psychology, University of Southern California, Los Angeles, #School of Social Science, University of California, Irvine, CA, USA*

*Predictions from a structured cortical model led us to test the hypothesis that music training enhances young children's spatial–temporal reasoning. Seventy-eight preschool children participated in this study. Thirty-four children received private piano keyboard lessons, 20 children received private computer lessons, and 24 children provided other controls. Four standard, age-calibrated, spatial reasoning tests were given before and after training; one test assessed spatial–temporal reasoning and three tests assessed spatial recognition. Significant improvement on the spatial–temporal test was found for the keyboard group only. No group improved significantly on the spatial recognition tests. The magnitude of the spatial–temporal improvement from keyboard training was greater than one standard deviation of the standardized test and lasted at least one day, a duration traditionally classified as long term. This represents an increase in time by a factor of over 100 compared to a previous study in which listening to a Mozart piano sonata primed spatial–temporal reasoning in college students. This suggests that music training produces long-term modifications in underlying neural circuitry in regions not primarily concerned with music and might be investigated using EEG. We propose that an improvement of the magnitude reported may enhance the learning of standard curricula, such as mathematics and science, that draw heavily upon spatial–temporal reasoning.* [Neurol Res 1997; **19**: 2–8]

*Keywords: Columnar cortical model; piano keyboard lessons; computer lessons; spatial recognition; educational implications; EEG*

## INTRODUCTION

Theoretical and empirical reports have suggested a relationship between musical and spatial reasoning abilities[1–6]. Leng and Shaw's model provides a neurobiological argument for a causal link between music and spatial–temporal reasoning[7]. Based on Mountcastle's[8] columnar[8–9] organizational principle for cortical function, the trion model[10–12] proposes that the inherent spatial–temporal firing patterns of highly structured, interconnected groups of neurons have the built-in ability to recognize, compare and find relationships among patterns[12]. This neural process may be responsible for the performance of spatial recognition tasks, such as classifying and recognizing physical similarities among objects. According to the model[7], the evolution of these relationships among neural firing patterns into specific temporal sequences for tens of seconds over large portions of cortex allows for the performance of other more complex spatial tasks requiring spatial–temporal reasoning. Spatial–temporal reasoning involves maintaining and transforming mental images in the absence of a physical model and is required for highe brain functions such as chess, mathematics anc engineering.

Music cognition, it was argued, should also requir these temporal sequences of neural activity[7,13–14]. A fundamental property of these evolving patterns c neural activity is that they can be readily strengthene through experience or learning[10–11]. Although highe brain functions are typically associated with specific localized regions of cortex, all higher cognitive abilitie draw upon a wide range of cortical areas[15]. Leng an Shaw[7] proposed that exposure to music might excite an enhance the cortical firing patterns used in spatial temporal reasoning, thus affecting cognitive ability i tasks that share this complex spatial–temporal neur code. Behavioral research based on these predictior found that college students scored significantly high on spatial–temporal reasoning tasks after listening to Mozart sonata (K. 448), but not after listening to silenc or to minimalist music[16–17]. While these studi established the existence of a causal relationsh between music and spatial–temporal reasoning, tl effect lasted only ten minutes. Leng and Shaw suggest that music training of young children, whose cortices a

Correspondence and reprint requests to: Gordon L. Shaw PhD, Center for Neurobiology of Learning and Memory, and Department of Physics, UCLA, Irvine CA 92697-4575, USA. Accepted for publication September 1996.




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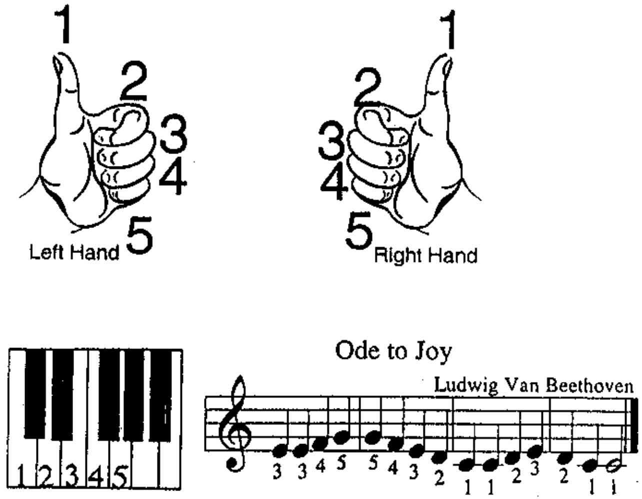


**Figure 2**: Numerical finger association used in the piano keyboard instruction. The children are taught to associate their fingers as numbered in **A** with the numbered keys on the piano keyboard as shown for the right hand in **B**. Shown in **C** is an example of a melody for the right hand that the children are able to play by the third month of lessons. Right and left hand coordination exercises are introduced at the outset of training. Hands together exercises are incorporated in the second and third months. Position changes or shifting to a different tonal center are introduced in the fourth and fifth months

personal home computer to the preschools for the 10-min private lessons. The children were taught to open entertaining, age-appropriate, commercial software programs by copying simple DOS commands. Most of the children mastered this after one month. The software was designed to teach reading and simple arithmetic skills. Letter recognition varied for each student. Some children could identify many letters at the start, whereas most children could identify 8 to 10 letters after three months. The children also learned sentence structure by completing sentences such as 'I am thankful for …'. Counting skills and number recognition were also taught. On average, children were able to count three objects after one month and six objects after three months. The lessons did not involve the use of the mouse or software programs which centrally featured music.

The No Lessons group controlled for task artifacts. For example, a particular task score may improve because the children enjoy it more with age, rather than as a function of treatment.

## Testing

Prior to training, we tested all the children's spatial reasoning with four tasks from the Performance sub-test of the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R)[18]. Children were tested individually at the preschools. In the Object Assembly (OA) task, which measured spatial–temporal skill, the child arranged pieces of a puzzle to create a meaningful whole. Performing this task required forming a mental image of the completed object and rotating the puzzle pieces to match the image. Performance was facilitated by putting the pieces together in particular orders, defining the spatial–temporal nature of the task. For example, in the animal puzzle (*Figure 3A*), beginning with the head facilitated performance, but placing the head and tail together first led to difficulty in correctly placing the middle pieces. The other five WPPSI-R tasks measured spatial-recognition. We used the following three: (i) Geometric Design required children to visually match and draw displayed model figures (*Figure 3B*), (ii) Block Design required the child to match depicted patterns using flat, two-colored blocks, and (iii) Animal Pegs required children to place the correctly colored pegs in holes below a series of pictured animals. These spatial-recognition tasks required matching, classifying, and recognizing similarities among displayed objects. Sequential order was not relevant. Children were re-tested on all tasks after six to eight months of lessons. The No Lessons group was re-tested at the same time as the other children.

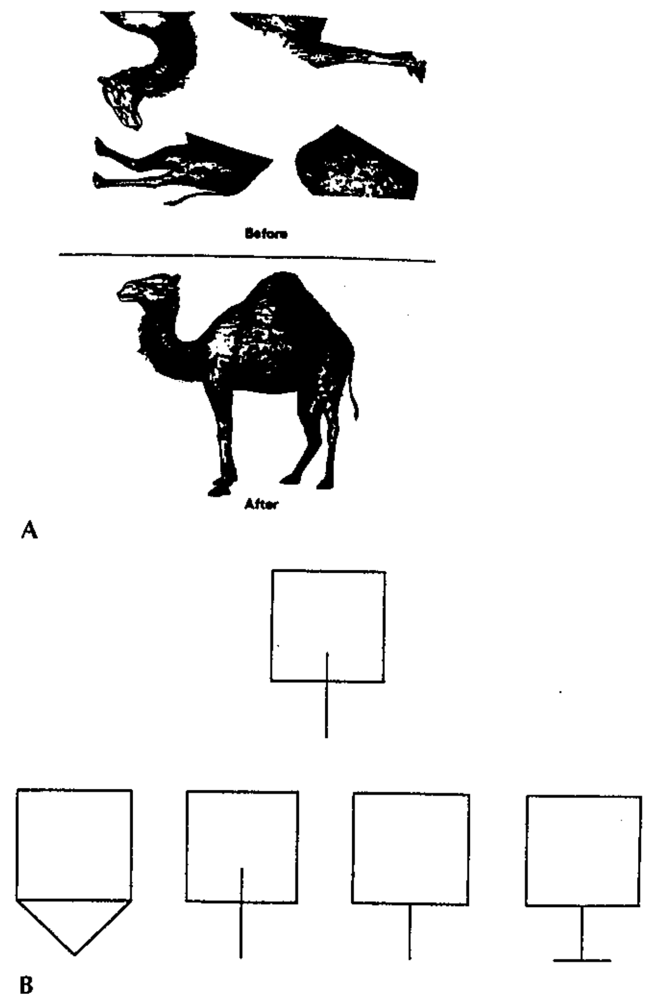


**Figure 3 A**: Schematic representation of the Object Assembly task, requiring spatial–temporal reasoning. The child arranges pieces of a puzzle to create a meaningful whole. **B**: Schematic representation of the Geometric Design task, requiring spatial recognition. The child points to the bottom-row figure that matches the figure in the top row

### Scoring

As specified by the WPPSI-R scoring instructions[18], raw scores were based on the number of errors made within a specified time period, and bonus points were awarded for accuracy and speed. Scaled scores were calculated for children at three-month age intervals. The established mean for all WPPSI-R tests ($M$) is 10 points, with all standard deviations ($\sigma$) equal to 3.

Testing procedures followed those recommended by the Wechsler test manual[18]. Testing sessions lasted 60–75 min, and were conducted in the morning. Children who became distracted during testing were given a 5-min break before testing was resumed. Testing during the first year was performed by the first author. During the second year, testing was performed by research assistants blind both to the hypothesis of the experiment and to group assignment. Preliminary analysis conducted on these two sets of data showed no differences, so the data were pooled. All tasks were independently scored by two researchers blind to condition assignment. Inter-rater reliability ranged from $r = 0.995$ to $r = 1.0$.

## RESULTS AND DISCUSSION

*Figure 4A* shows how each of the four different types of training effect spatial–temporal abilities by presenting the before and after training Object Assembly (OA) means for each of the four training groups. This figure reveals that music training for the Keyboard group produced a dramatic overall increase in OA scores (as evidenced by a pre-training mean of 9.79 and a post-training mean of 13.41) while none of the other training groups showed any appreciable change. To verify the obvious difference, a One-Way ANOVA was performed on the change scores with the four training groups (Keyboard, Computer, Singing, No Lessons) as treatments. As expected, this analysis produced highly significant differences between the four groups ($F(3,74) = 3.87$, $p < 0.0001$).

Even more revealing were the results derived from a subsequent assessment of multiple paired comparisons between treatment groups where Bonferroni (Dunn) T tests were used to assess differences between means of pre–post difference scores for pairs of treatment groups. Using this conservative method, the Keyboard group nonetheless differed significantly ($p < 0.01$) from each of the other three groups. No pairing of the remaining three treatment groups produced a rejection of the associated null hypothesis, even when the alpha level was set as high as 0.99 ($\alpha = 0.99$). As shown in *Table 1*, the pattern of these results is quite striking.

ANOVAs performed on the children's scores on the other tests (Geometric Design, Block Design and Animal

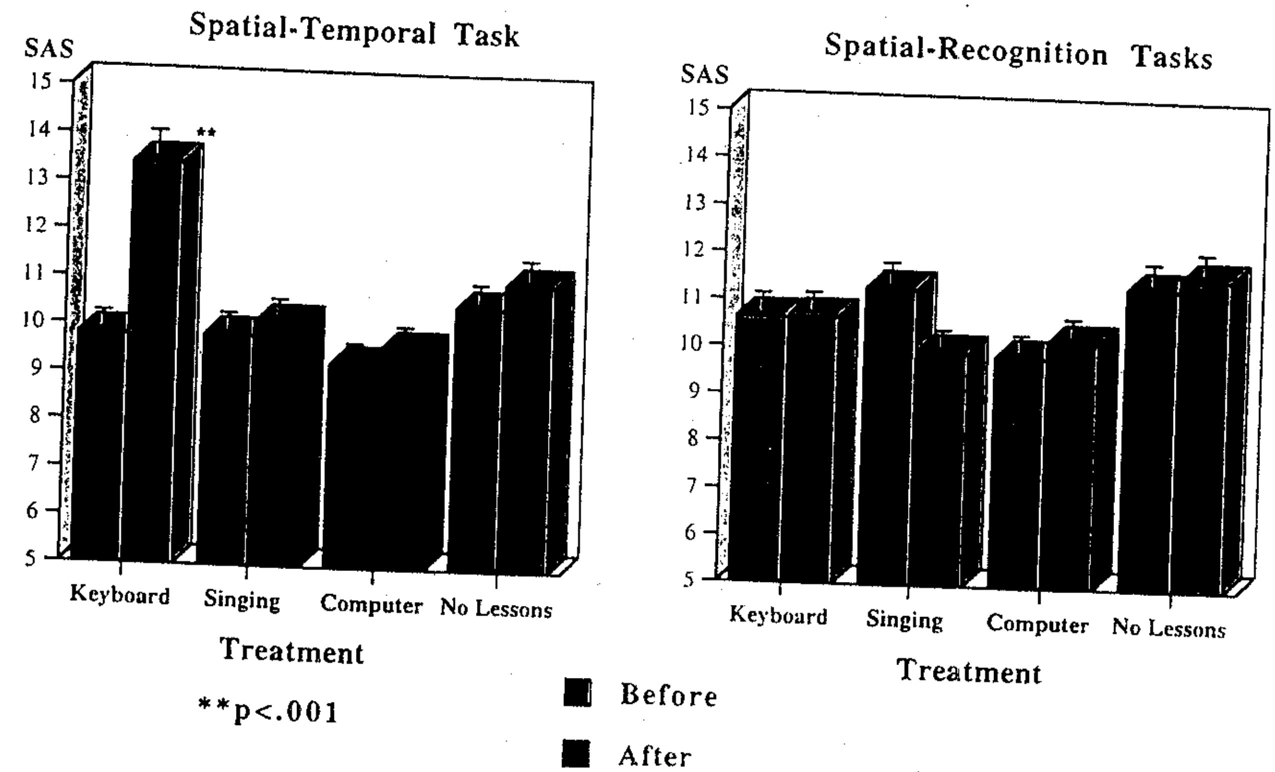


**Figure 4 A**: The means for the OA standard age scores (SAS) with standards errors are plotted measuring spatial–temporal reasoning for the Keyboard, Singing, Computer and No Lessons groups before and after treatment. The standard deviations for each of these groups, before and after training, respectively, are 2.61 and 2.91, 3.91 and 3.07, 3.27 and 3.07, 2.77 and 2.25. The Keyboard group improved significantly following lessons whereas the other groups did not. **B**: The spatial-recognition SAS means with standard errors for the four groups before and after treatment. The standard deviations for each of these groups, before and after training, respectively, are 2.25 and 1.86, 1.68 and 1.97, 2.53 and 2.82, 1.55 and 1.57. No groups improved significantly

(WPPSI-R's $\sigma = 3$), as compared to the expected 5 or 6 children (16%) by the Gaussian model. *Figure 5B* shows the histogram for the three combined control groups. Only six of the 44 children (14%) improved by 3 or more points.

Memory researchers differentiate between short-term and long-term memory[19]. The latter, lasting hours or longer, is associated with enduring synaptic changes, perhaps long-term, potentiation[20–21]. To determine if the enhancement found in this study was long-term, we compared the ΔOA scores of the children who were tested one day or more after their last keyboard lesson to those of the children who were tested less than one day afterwards. We found no significant difference. A *t*-test for independent samples performed on the ΔOA scores of the 27 children who were tested one day or more after their last piano keyboard lesson ($M = 3.59$) vs. the ΔOA scores of the 7 children who were tested less than one day afterwards ($M = 3.71$) was not significant ($t_{(1,32)} = 0.09$, ns). This indicates that the enhancement on the OA spatial–temporal task from piano keyboard training lasted at least one day, and is considered by memory researcher standards to be long-term[19–21].

Our previous findings of enhanced short-term spatial–temporal reasoning in college students after listening to a Mozart sonata suggest that music can prime regions of cortex responsible for spatial–temporal reasoning[16–17]. (An EEG coherence study of this short-term enhancement of spatial–temporal reasoning has been performed[22].) The long-term enhancement found in the current study represents an increase by more than a factor of 100 over the previous listening experiments[16–17]. This study suggests that music training, unlike listening, produces long-term modifications in underlying neural circuitry (perhaps right prefrontal and left temporal cortical areas as indicated in EEG coherence studies[22]) in regions not primarily concerned with music. The magnitude of the improvement in spatial–temporal reasoning from music training was greater than one standard deviation, equivalent to an increase from the 50th percentile on the WPPSI-R standardized test to above the 85th percentile.

The precise duration of the enhancement and the possible existence of a critical period need to be examined. An exploration of the aspects of music training that are responsible for the enhancement must be undertaken, so that the optimum training method can be identified. Although our study was limited by the resources we had available, the ideal study would draw participants from the same preschool at the same time, thereby eliminating any possible confounds due to preschool demographics or age. It should be noted, however, that we found no significant differences on measures of task improvement based on these factors. Further research is necessary to identify other spatial-temporal reasoning tasks that may be enhanced by music training. And finally, explorations into the cortical representation[22] of spatial–temporal and musical reasoning coupled with supporting behavioral data are necessary.

It has been clearly documented[23] that young students have difficulty understanding the concepts of proportion (heavily used in math and science) and that no successful program has been developed to teach these concepts in the school system. We predict that an enhanced ability to evolve temporal sequences of spatial patterns as a result of music training will lead to an enhanced conceptual mastering of proportional reasoning. This is a strong proposal which should be investigated in future research.

The high proportion of children who evidenced this dramatic improvement in spatial–temporal reasoning as a result of music training (*Figure 5A*) should be of great interest to scientists and educators, particularly because the duration of the effect lasts at least one day. We suggest that an improvement of this magnitude may enhance the learning of standard school curricula that draw heavily upon spatial–temporal reasoning abilities, such as mathematics and science.


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