

Effects of Piano, Singing, and Rhythm Instruction on the Spatial Reasoning of At-Risk Children

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1. ABSTRACT

Previous research has demonstrated that preschool children score higher on spatial tests following piano instruction. Three studies were conducted to answer three questions regarding these effects: (1) Which cognitive processes are enhanced by piano instruction? (2) Do different types of instruction have differential effects? (3) Are these effects durable and generalizable? In Study 1, at-risk preschool children were provided with weekly piano instruction, computer instruction, or no instruction for two years. Children were pre- and post-tested using a large battery of standardized cognitive tests. Results indicated that children who received piano instruction scored significantly higher than control children on tests requiring spatial and/or temporal abilities. In Study 2, children received instruction in piano, singing, or rhythm instruments. A control group of children received no instruction. We administered the same battery of tests as in Study 1. All music groups scored higher than controls on spatial and temporal tasks. The rhythm group scored higher than the piano and singing groups on temporal tasks. The piano and singing groups' scores did not differ. Study 3 compared the scores of the children who received music lessons to those of Head Start children who did not receive instruction, at-risk children who were not enrolled in Head Start, and middle-income elementary school children. The music groups continued to score higher than all other groups on spatial and temporal tasks two years after instruction ended. The rhythm group continued to score higher than controls on temporal and mathematics tests. No effects were found for verbal, memory, or reading tests.

2. BACKGROUND/AIMS

Several studies have suggested that music

instruction improves preschool and elementary school children's spatial abilities (1). In a typical study, the "treatment" group received private instrumental or school music instruction, while "control" groups either received no treatment or special training in something other than music. Children were usually pre-tested prior to the instruction and post-tested several months or years later. Outcome measures included tests measuring spatial-temporal abilities (i.e., tasks defined as those requiring mental rotation and/or multiple solution steps for two- or three-dimensional figures in the absence of a physical model). The mean effect size found by Hetland's meta-analysis involving 15 independent studies and 709 subjects was $d = .79$, with 100% of the effect sizes greater than zero.

It has been suggested that these findings may be due to differences between musicians and non-musicians in brain structure and function as a result of their music instruction (2, 3, 4, 5). Researchers have found that musicians who began piano instruction before age 7 had a larger cross-section of the anterior corpus callosum (6). Furthermore, dipole moments of the digits of the left hand were found to be significantly larger in violinists compared to non-musicians, with the greatest effects found for musicians who began instruction before age 12 (7). A follow-up MEG study found auditory cortex dipole moments for piano tones were enlarged by about 25% in musicians relative to non-musicians (8). Again, there was a positive correlation between effect size and when participants initiated instruction: musicians who began instruction before age 9 showed the largest effects. Pantev et al. concluded that "use-dependent functional reorganization extends across the sensory cortices to reflect the pattern of sensory input processed by the participant during development of musical

skill” (p. 811). Finally, researchers using MEG measured violinists’ and trumpeters’ cortical representations for violin and trumpet tones compared to sine wave tones (9). The researchers found enhanced representations for timbres associated with the instrument of training, with trumpeters showing enhancement for trumpet tones and violinists showing enhancement for violin tones. This study suggests that experience with different musical instruments may affect brain function in different ways.

The research reported here is the product of three closely related studies involving economically disadvantaged preschool children. All children were enrolled in Head Start, a federally funded preschool program designed to prepare economically disadvantaged children for public school. Modal household incomes in our sample ranged between \$10,400 and \$15,600. The first study, conducted over two years, attempted to replicate and extend the finding that piano instruction provided to preschool children improved spatial-temporal scores compared to children who received computer instruction or no special training. The purpose of the second two-year study was to determine if the type of music instruction children received had measurably different effects on cognition. Most researchers agree that musical skill is an alliance of a number of separate and relatively independent abilities. We proposed that early music instruction emphasizing different musical skills would produce correspondingly differential effects on cognitive performance. Supporting this proposition, a recent study suggests that several years of string and percussion instruction selectively improved auditory frequency and duration discrimination thresholds compared to no instruction (10). The second study thus compared the effects of three types of music training—piano, singing, and rhythm—each of which highlights a partially non-overlapping set of musical properties. Finally, the third study was conducted to investigate if the effects found in the first and second studies endured into elementary school, and further to examine the effects of the previously-initiated instruction on academic skills.

3. METHODS/RESULTS

Study 1

The first experiment was designed to test three- and four-year-old at-risk children’s spatial and temporal skills before (T1) and after (T2) two academic years of weekly individual piano instruction. Two further groups of children were included in the design to control for the Hawthorne Effect. One group received individual computer instruction matched in frequency and duration to the piano instruction, and the other group received no special training. Five standardized tests were administered to assess the specific cognitive processes that are enhanced through music training. Specific predictions were made regarding the children’s performance on each test. Overall, we predicted that the children who received the piano instruction would improve more and score significantly higher than the children in the comparison and control groups on tasks classified as having spatial and/or temporal content. We further predicted that tasks that do not tap spatial or temporal abilities would not be affected by the instruction.

3.1.1. Methods

Eighty-seven children (mean age 3 years 3 months at T1, 45 girls, 42 boys) were randomly assigned to three groups: Piano (n=33), computer (n=28) and control (n=26). We pre- and post-tested all the children using subtests of the Kaufman Assessment Battery for Children (K-ABC), the Developmental Test of Visual Perception (DTVP-2), the Test of Auditory Perceptual Skills-Revised (TAPS-R), and the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R). These tests measure different aspects of spatial-temporal, visuo-spatial, and auditory skills. Overall, we administered twenty-six sub-tests. All testing was performed by research assistants blind to experimental conditions and hypotheses.

3.1.2. Results

An alpha level of .05 was used for all statistical tests. As predicted, children who received music instruction scored significantly higher than those who received computer or no instruction only on

tasks requiring spatial and temporal skills. Consider, for example, the WPPSI-R's Object Assembly (OA) task ([Figure 1](#)).

A two-factor (condition, testing) mixed analysis of variance (ANOVA) found a main effect for condition ($F_{(2,84)} = 8.99, p < .000$), a main effect for testing ($F_{(1,84)} = 97.58, p < .000$), and an interaction between condition and testing ($F_{(2,84)} = 49.10, p < .000$). Although the three groups' scores did not differ in T1, the piano group scored significantly higher than computer or control groups ($p < .000$ both) in T2.

Tasks that also improved significantly following piano instruction included four tasks from the K-ABC (Hand Movements, Magic Window, Gestalt Closure, and Arithmetic), five tasks from the DTVP (Eye-Hand Coordination, Spatial Relations, Form Constancy, Visual Closure, and Figure-Ground), and two tasks from the TAPS (Auditory Sentence Memory (Sequencing) and Auditory Processing (Thinking and Reasoning)). In short, spatial and/or temporal tasks were improved following piano instruction, whereas verbal tasks, matching tasks, copying tasks, and memory tasks were not significantly affected. None of these tasks were significantly improved by the computer instruction, although children who received computer lessons did score significantly higher on the K-ABC's Expressive Vocabulary and Faces and Places tasks than children in the piano or control groups.

3.2. Study 2

At-risk preschool children received piano, singing, rhythm, or no instruction for two years. All children were pre- and post-tested using the same standardized tests as in Study 1. We predicted improvement in spatial-temporal tasks following all types of music instruction, improvement in mental imagery tasks following singing instruction (due to singing's strong reliance on auditory imagery), and improvement in temporal tasks following rhythm instruction (due to rhythm training's emphasis on the temporal qualities of music).

3.2.1. Methods

One-hundred-twenty-three male and female Head

Start preschool children of mixed ethnicity were randomly assigned to four conditions: Piano ($n=34$), singing ($n=28$), rhythm ($n=35$) and control ($n=26$). As in Study 1, children in the music groups received weekly individual instruction at their Head Start school for a period of 48 weeks over two years. Children in the control group received no special training. We pre- and post-tested all the children using the same tests used in Study 1: K-ABC, DTVP-2, TAPS-R, and WPPSI-R. Again, we administered twenty-six sub-tests.

3.2.2. Results

Due to the large number of sub-tests administered, here we present only the data from one spatial-temporal task (Object Assembly—OA), one mental imagery task (Form Constancy—FC), and one temporal task (Magic Window—MW) to demonstrate the veracity of our predictions. The data represent typical results for these three task categories.

An alpha level of .05 was used for all statistical tests. A two-factor (condition, testing) mixed analysis of variance (ANOVA), with condition as the between-subjects factor and testing as the within-subjects factor, was performed on the pre- and post-test scores of the OA (spatial-temporal) task. The data are presented in [Figure 2](#).

We found a main effect for testing ($F_{(3,119)} = 129.44, p < .001$) and an interaction between testing and condition ($F_{(1,119)} = 14.52, p < .001$). The main effect for condition was not significant ($F_{(3,119)} = 2.50, p = .06$). The pre-test scores for the four groups did not differ. However, LSD tests revealed that the post-test scores of the piano, singing, and music groups were significantly higher than those of the control group ($p < .001$, all). The standard scores of the three music groups improved significantly from pre-test to post-test ($p < .001$). The post-test scores of the three music groups, however, did not differ from each other.

To illustrate the effects of music instruction on mental imagery, we present here the data for the FC task. We performed a two-factor (condition, testing) mixed ANOVA on the pre- and post-test

raw scores of this task. These data are graphed in [Figure 3](#).

We used standard scores rather than raw scores because the FC task is standardized for children age 4 to 11. We found main effects for condition ($F_{(3,119)} = 3.05, p < .04$) and testing ($F_{(1,119)} = 175.56, p < .001$). The interaction between condition and testing did not reach significance ($F_{(3,119)} = 2.57, p = .06$). The pre-test scores of the four groups did not differ from each other. Because raw scores were used rather than scaled scores, LSD tests found significant differences between the pre- and post-test scores for all groups of subjects ($p < .001$, all). The improvement for the control group was presumably due to maturation. However, the post-test scores of the three music groups were significantly different from the post-test scores of the control group (piano vs. control and singing vs. control: $p < .001$; rhythm vs. control: $p > .01$). The post-test scores of the three music groups did not differ significantly.

Finally, we performed a two-factor (condition, timing) mixed ANOVA on the scaled pre- and post-test scores of the Magic Window (temporal) task. The data are shown in [Figure 4](#).

The analysis revealed main effects for condition ($F_{(3,119)} = 6.63, p < .001$) and testing ($F_{(1,119)} = 138.97, p < .001$), and an interaction between condition and testing ($F_{(3,119)} = 14.83, p < .001$). Although the four groups' pre-test scores did not differ, all music groups scored significantly higher in post-tests than in pre-tests ($p < .001$, all). The control group's pre- and post-test scores did not differ significantly ($p < .15$). The post-test scores of the three music groups were significantly higher than those of the control group (singing vs. control and rhythm vs. control: $p < .001$; piano vs. control: $p < .03$). Although the post-test scores of the piano and singing groups did not differ significantly ($p < .13$), the post-test scores of the rhythm group were higher than both the piano and singing groups ($p < .001$, both). This trend was also found for the other temporal tasks we administered—the Number Recall, Magic Window, and Arithmetic tasks of the KABC, the Figure Ground task of the DTVP, and the

Auditory Number Memory Forward, Auditory Number Memory Backward, and Auditory Sentence Memory (Sequencing) tasks of the TAPS.

3.3. Study 3

The third study was designed to compare the scores of the children who received music lessons in studies 1 and 2 to three groups of grade-matched children: (1) Head Start children who did not receive music instruction; (2) at-risk children who were not enrolled in Head Start, and (3) middle-income children.

3.3.1. Methods

We re-tested the children who participated in the control ($n=24$) and piano ($n=31$) groups in Study 1 (now in second grade) as well as the music children who participated in Study 2 (now in kindergarten). We were able to track 76 of the 97 music children from Study 2 (piano, $n=27$, singing, $n=20$, rhythm, $n=29$). All children were tested individually in their homes or schools.

The children in Studies 1 and 2 were administered the K-ABC and the Wechsler Individual Achievement Test (WIAT), a test that measures basic reading, mathematics reasoning, spelling, reading comprehension, numerical operations, listening comprehension and oral expression. We also administered the K-ABC and the WIAT to 27 at-risk kindergartners, 24 at-risk second-graders, 32 middle-income kindergartners, and 28 middle-income second graders.

3.3.2. Results

In brief, we found that the children who received music instruction in Study 1 (now in second grade) continued to score higher on three of the four K-ABC tasks that were previously enhanced by the instruction (Hand Movements, Gestalt Closure, and Arithmetic). The fourth task, Magic Window, was not standardized for children older than age 5, and so was not administered. In addition, these children scored significantly higher on these tasks compared to second grade Head Start children who did not receive music instruction. When compared to grade-matched at-risk children who were not enrolled in Head Start,

the music group also scored significantly higher on the Expressive Vocabulary and Faces and Places tasks. The children who were enrolled in Head Start but did not receive music instruction scored significantly higher than at-risk children who were not enrolled in Head Start programs on the Arithmetic, Expressive Vocabulary, and Faces and Places tasks. This suggests that although Head Start has little effect on spatial-temporal reasoning, it does influence children's abilities on other non-spatial tasks (and arithmetic). Finally, although no groups scored significantly higher than the middle income children on any of the tasks we administered, the scores of the children in the music group were roughly the same as those of the middle-income children on the spatial-temporal and arithmetic tasks. The other groups scored significantly lower than the middle-income children on all tasks. [Figure 5](#) shows the data for all groups for the Arithmetic task.

For the WIAT, we found that the music group scored significantly higher than the Head Start and at-risk children on the reading, spelling, reading comprehension, mathematical reasoning, numerical operations, and listening tasks. The Head Start children scored higher than the at-risk children on the reading, spelling, and reading comprehension tasks (but not the mathematical reasoning or numerical operations tasks). These findings demonstrate the specificity of the transfer of musical knowledge to numeracy and aural abilities. Finally the music children scored at the same level as the middle-income children on the mathematical reasoning and numerical reasoning tasks.

When we tested the children who participated in Study 2 (now in kindergarten), we found that the singing, piano, and rhythm groups scored higher on the K-ABC's Arithmetic, Expressive Vocabulary, Faces and Places, Hand Movements, and Gestalt Closure tasks than Head Start and at-risk children, whereas children in the rhythm group scored higher on the arithmetic sub-test than the singing and piano groups. This suggests that rhythm instruction has the strongest impact on mathematical reasoning. As with the second grade children, the kindergarten Head Start

children scored higher than the at-risk children on the Arithmetic, Expressive Vocabulary and Faces and Places tasks. Remarkably, although the piano and singing groups scored equal to the middle-income group on the spatial-temporal and arithmetic tasks, the rhythm group actually scored significantly higher than the middle-income children on the arithmetic test. They also scored higher than the middle-income children on the mathematical reasoning and numeracy tests of the WIAT.

4. CONCLUSIONS

This research suggests that learning music is an important developmental activity that may help at-risk children compete academically on a more equal basis with their middle-income peers. Although the Head Start program did improve children's performance on several of the tasks we administered, improvement on the spatial-temporal tasks was confined to those children who received music instruction. The presence of a Hawthorne effect was ruled out by the control groups employed in Study 1, and the effects of the music instruction were found to continue for at least two years after the intervention ended.

The data reported here provide partial support for our hypothesis that different types of music instruction affect different aspects of spatial-temporal cognition. Consistent with previous research and Study 1, Study 2 found that children who received music instruction scored significantly higher on spatial-temporal tasks than children who did not. However, our prediction that the mental imagery scores of children who study singing would be higher than children who study piano or rhythm instruments was not borne out. For example, the singing group's scores on the Form Constancy task, a measure of mental imagery, were not higher than those of the other two music groups. However, all groups did score higher than the control group.

We further predicted that children who studied rhythm instruments would score higher on temporal tasks than children who studied either piano or singing. This prediction was supported by the data. For example, although the Magic

Window post-test scores of children in the piano and singing groups were higher than those of controls, children in the rhythm group scored significantly higher in post-tests on this and other temporal tasks than either the piano, singing, or control groups. This suggests that training in a rhythm instrument may influence the neural circuitry involved in judging temporal duration. Future research exploring the neurophysiological basis of these findings will determine whether these selective effects are accompanied by changes in the structure and function of the brain.

5. REFERENCES

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6. ACKNOWLEDGMENT

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Figure 1. Mean Object Assembly (OA) pre- and post-test standard scores for piano, computer, and control groups. OA is a spatial-temporal task that requires the child to assemble a series of cardboard pieces into a familiar whole in the absence of a physical model. Error bars represent 1 standard error of the mean (SEM). [[Click hyperlink to return to text.](#)]

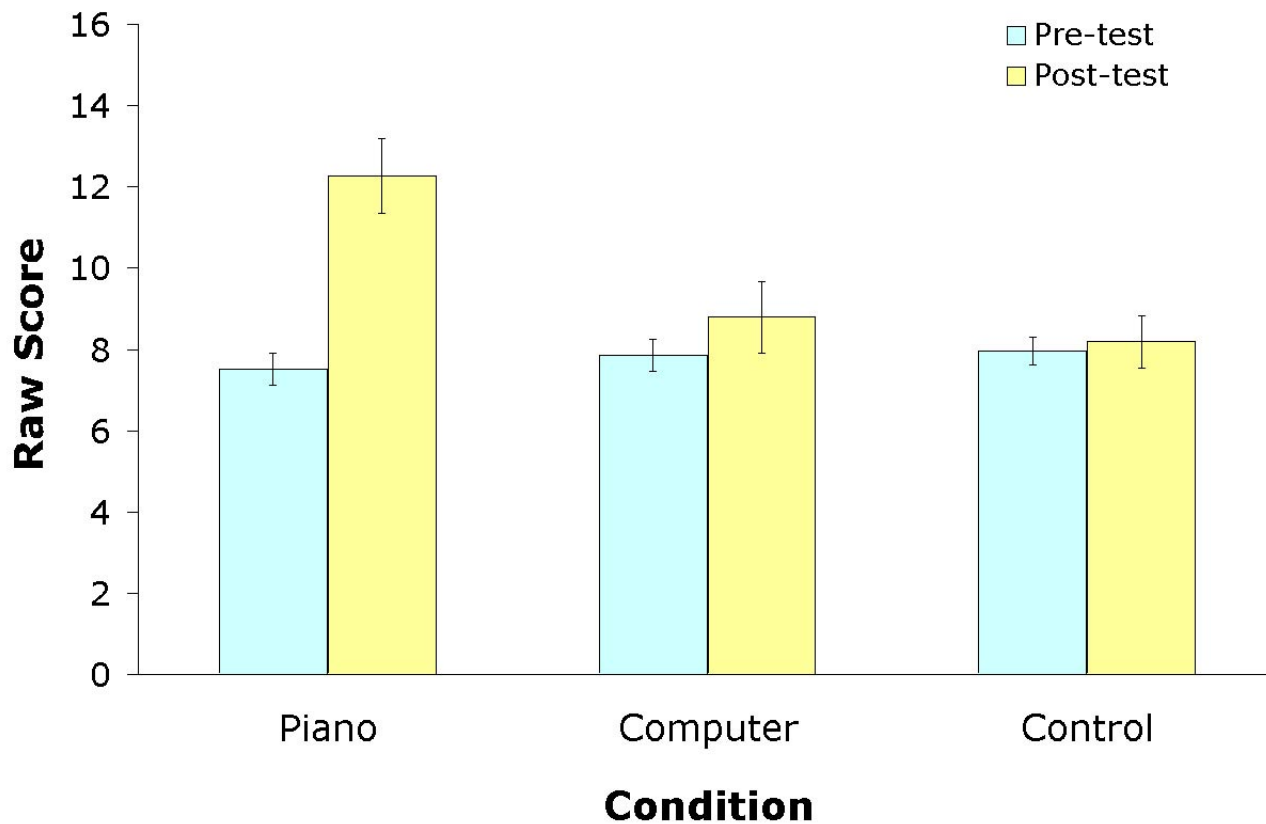


Figure 2. Mean Object Assembly (OA) pre- and post-test standard scores for piano, singing, rhythm, and control groups. Error bars represent 1 SEM. [[Click hyperlink to return to text.](#)]

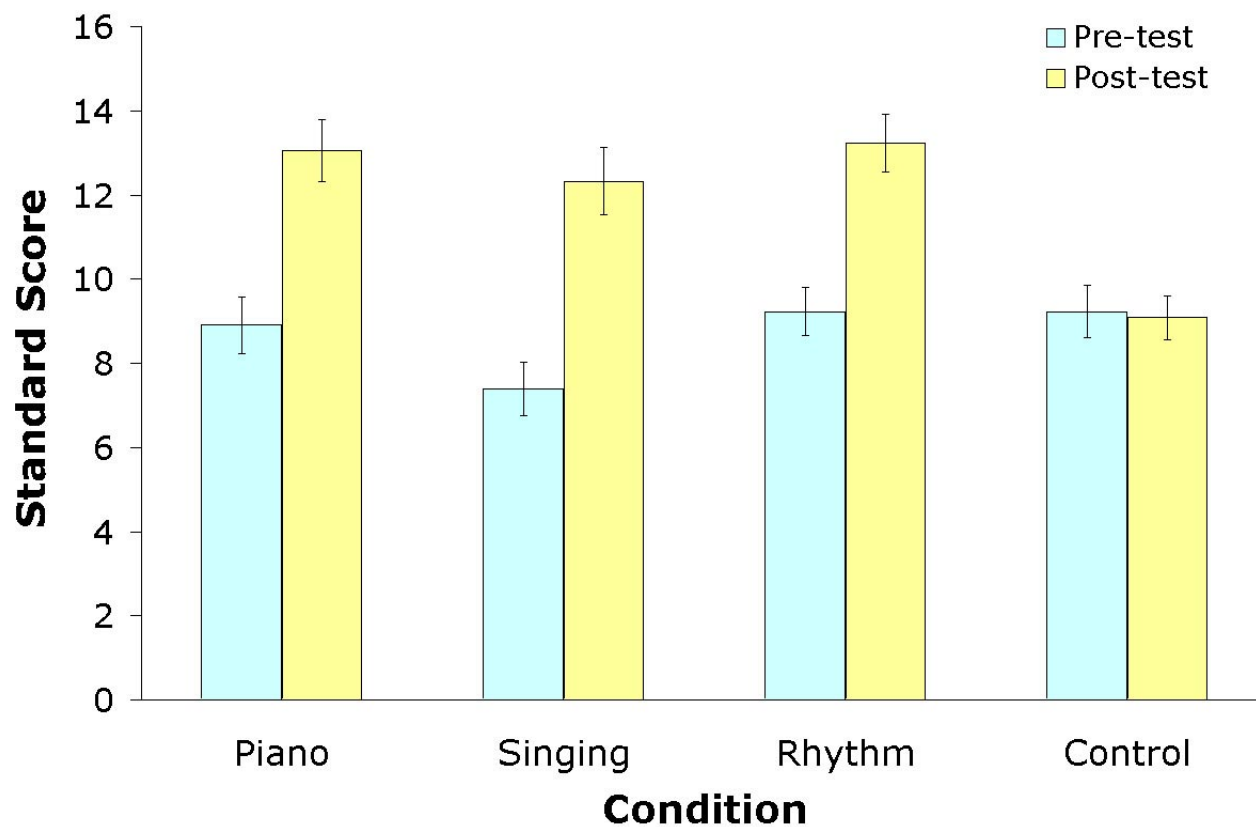


Figure 3. Mean Form Constancy (FC) pre- and post-test raw scores for piano, singing, rhythm, and control groups. FC is a mental imagery task that requires the child to recognize the central features of an object when it appears in different sizes, shapes, shadings, textures, and positions. Error bars represent 1 SEM. [[Click hyperlink to return to text.](#)]

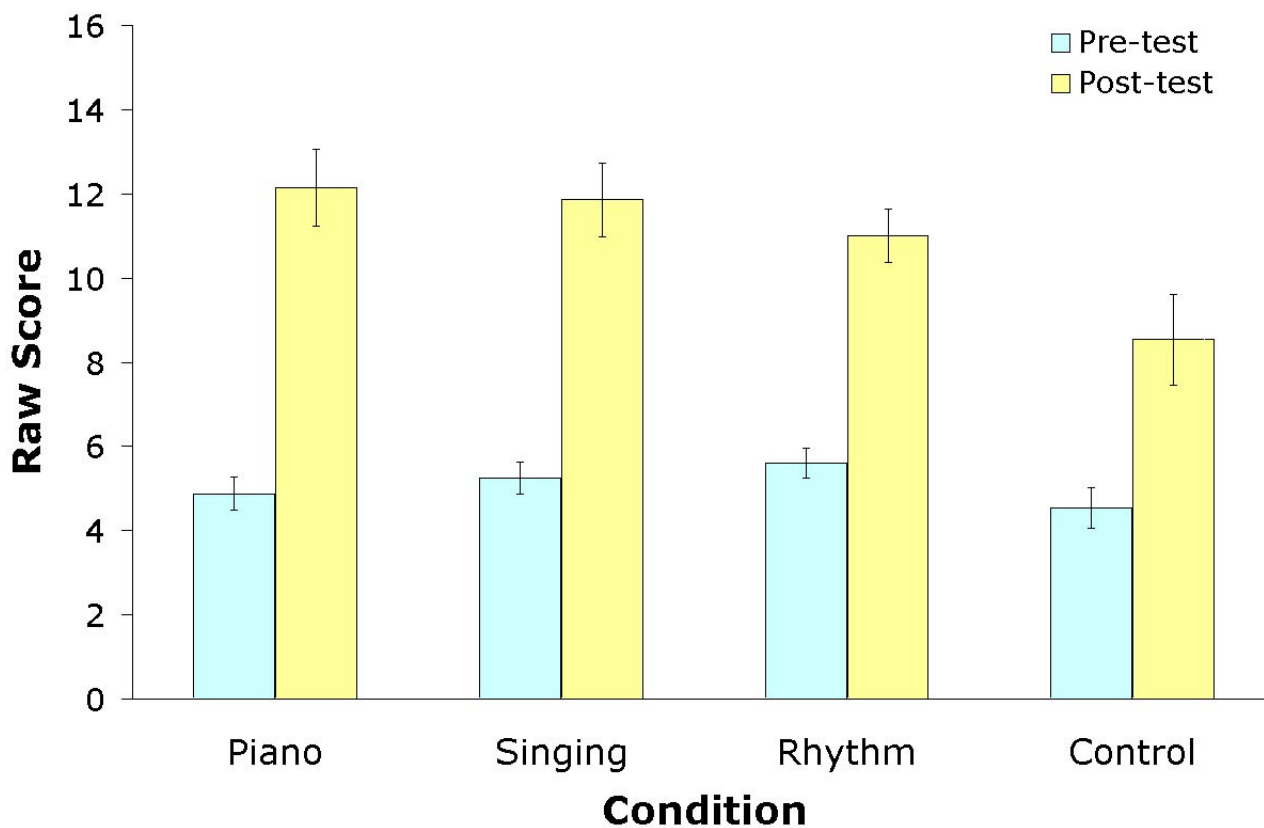


Figure 4. Mean Magic Window (MW) pre- and post-test standard scores for piano, singing, rhythm, and control groups. MW is a temporal task that measures the child's ability to identify and name an object whose picture is rotated behind a narrow slit, so that the picture is only partially exposed at any given point in time. Error bars represent 1 SEM. [[Click hyperlink to return to text.](#)]

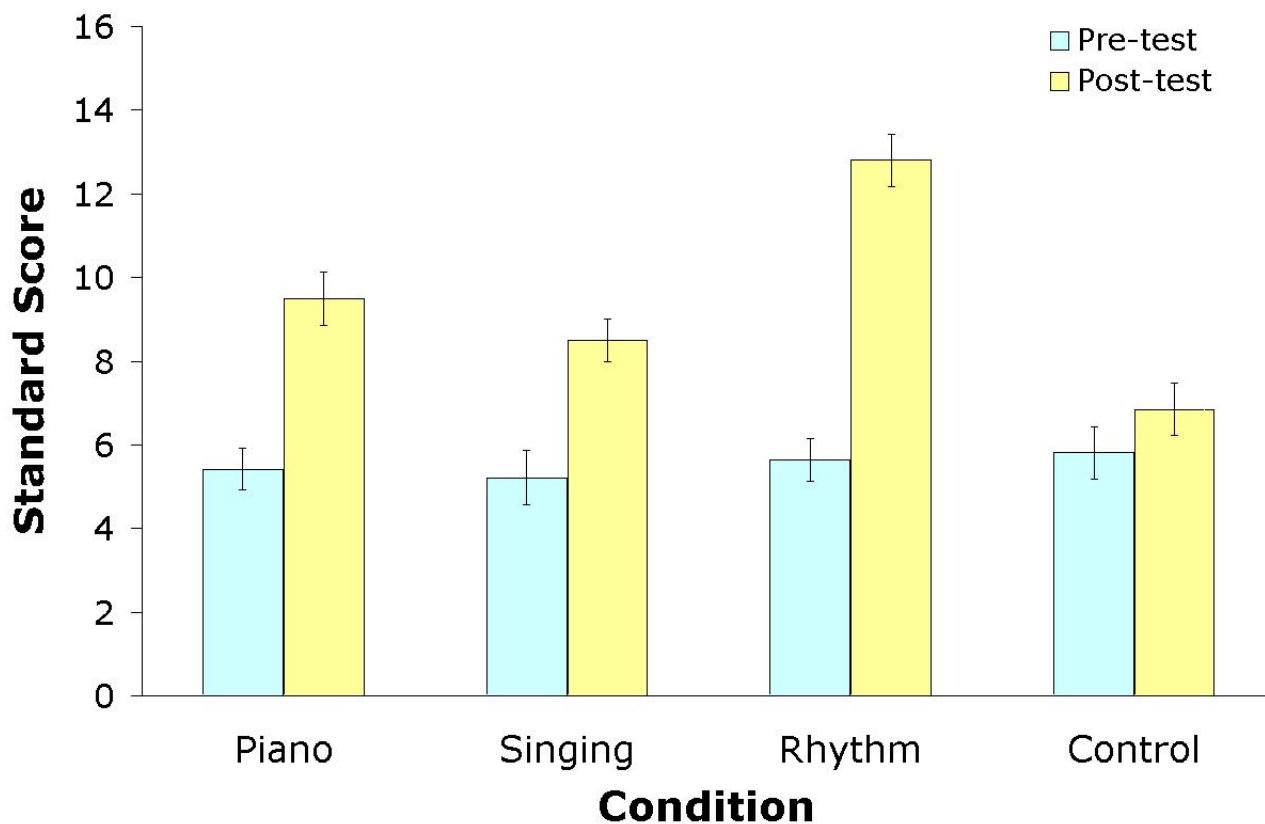


Figure 5. Mean Arithmetic standard scores for music, Head Start, at-risk, and middle income groups. Music and Head Start children participated in Study 1. Error bars represent 1 SEM. [[Click hyperlink to return to text.](#)]

