EARLY CHILDHOOD
CONNECTIONS
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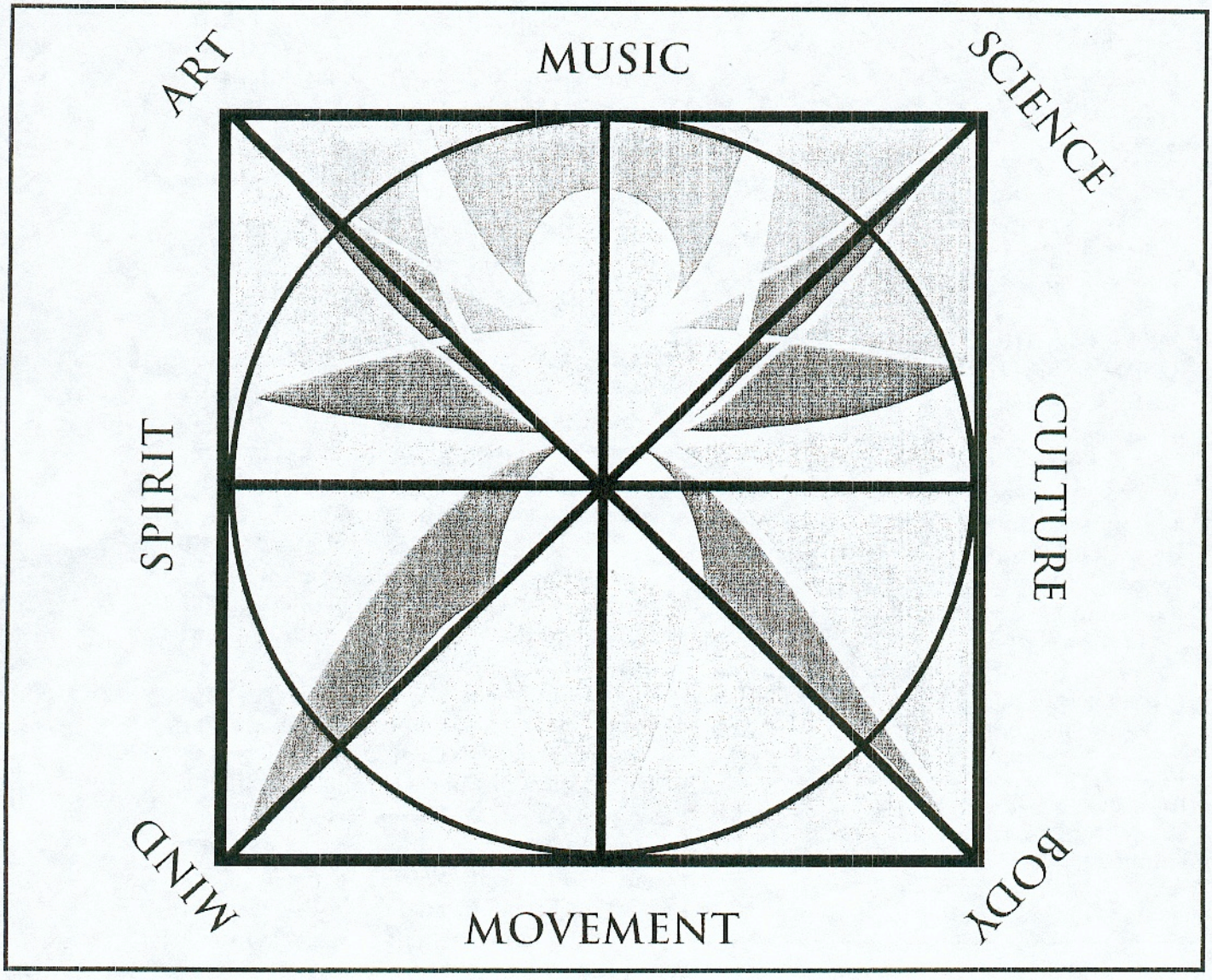
MUSIC DEVELOPS ALL SPHERES



THE MUSIC-MATH CONNECTION

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The causal connection between music training and enhanced learning of difficult math concepts by young children has been firmly established and is being further investigated and implemented in selected schools. The purpose of this paper is to make this causal connection clear and intuitive. We start by reviewing the past 15-year history of research, which has established the *causal* connection between music and children's innate spatial-temporal (ST) reasoning (i.e., making a mental image and thinking ahead in space and time, as in chess, music, or math). A key new step presented here that clearly and intuitively connects music and math is the mapping of a standard music score onto ST patterns, which we propose will allow very young children to start playing the piano keyboard.

WHY MASTERING OR UNDERSTANDING MATH IS SO CRUCIAL

The consequences of children not being able to *master* math are enormous. With a good teacher, a motivated child will master the English language and will do well on standardized math tests. While necessary and important, this is not sufficient for *understanding* or *mastering* math. Simply performing adequately on a standardized math exam — without actually mastering math — is not sufficient for opening the door to the high-tech world.

ABBREVIATION KEY:
Spatial-Temporal – ST
ST Animation Reasoning – STAR
Advanced Math Concepts – AMC
functional Magnetic Resonance Imaging – fMRI

If one thing is clear as we enter the third millennium, it is the growth of technology. Moreover, it is impossible to predict all the ways that (just to give a few examples) biological engineering, computers, lasers, microelectronic circuits, and robotics will effect our lives and job structure in the coming decades. However, it is safe to say that the number of semi-skilled jobs of the past will continue to dwindle. Furthermore, businesses are no longer competing with those next door or even in the next state, but must compete throughout the world. Given the increasing number of high-tech jobs, children who do not master math will have few choices and fewer opportunities.

SPATIAL-TEMPORAL MATH COMPLEMENTS LANGUAGE-BASED MATH

The US educational system relies almost entirely on language-based reasoning, while neglecting the complementary and innate ST reasoning. This oversight is a major flaw in our educational system. ST reasoning involves maintaining, transforming, and comparing mental images in space and time using symmetry operations (as in chess), and is fundamental in learning and using math and science concepts. Through the ST approach, children can understand and visualize math concepts and thereby solve the standard equations, symbols, and word problems required in the language-based approach.

Both types of reasoning — spatial-temporal and language-based — are necessary in teaching math. The most brilliant scientist of the 20th century, Albert Einstein, made many references to his own dependence on ST reasoning [1]:

> The words or the language, as they are written and spoken, do not seem to play any role in my mechanism of thought. The entities which seem to serve as elements in thought are certain signs and more or less clear images which can be voluntarily reproduced and combined.... Conventional words or other signs have to be sought for laboriously in a secondary stage.

Despite its crucial role in the thinking processes of most scientists, mathematicians, and engineers, ST reasoning is grossly neglected in US schools. And yet, research continues to demonstrate that ST abilities are innate to our structured brains. Our solution, the Music ST Math Program, allows children to visualize and understand difficult math concepts through their innate ST reasoning abilities.

MUSIC ST MATH PROGRAM: REVOLUTION IN MATH EDUCATION

The Music ST Math Program [2] exploits the structured brain's innate ability to do spatial-temporal reasoning. This three-part program complements and supplements the usual language-based (equations, symbols, and word problems) math programs found in schools as follows:

1) Music lessons enhance the brain's innate ability to do spatial-temporal reasoning.
2) The STAR (Spatial-Temporal Animation Reasoning) math videogame [3] software allows children to *visualize and understand* difficult math concepts.
3) Math integration lessons bridge ST learning to language-based learning. All three components are crucial. The Program works, and the children love it [2].

MUSIC–MATH CAUSAL CONNECTION RESEARCH

The connection between math and music goes back to the ancient Greeks, who considered music to be one of the four branches of math. The correlation between music training for children and their high math performance has been noted for some time; however, this could just be due to some "selection" process. For example, parents may be more likely to provide music training to children who already have high grades in math. The predictive theory of music training's *causally* enhancing math abilities began with the seminal work of Xiaodan Leng [4].

A series of landmark papers started with the trion model [3-9] of higher-brain function, based on the Mountcastle [10-11] columnar organization principle of the cortex. A "column" of neurons in the cortex represents the basic brain network [10-11]. The trion model (with three levels of firing activity) is an idealized mathematical realization of the breakthrough columnar principle. In the structured trion model, the innate internal language of higher-brain function is represented by spatial-temporal memory firing patterns (Fig. 1). The brain's innate ability to relate (through symmetry operations) these memory patterns is the unifying physiological mechanism of higher-brain function [3-9]. The finding that the structure and symmetry relationships of these memory patterns were those of recognizable styles of music [4] led to the realization [5] that "music could be used as a window into higher-brain function" and the prediction that specific music could enhance ST reasoning.

The trion model [3-9] motivated and guided these behavioral and neurophysiological experiments, all with major results. Results of these innovative and collaborative studies are organized here as follows:

- Mozart-effect listening experiments
- Direct tests of the trion model of higher-brain function
- Music training that enhances children's spatial-temporal reasoning and math learning.

- ***Mozart-effect listening experiments: 1-6***

1) Mozart-effect causal experiments with Frances Rauscher [12-14] found that after listening to the first 10 minutes of Mozart's Sonata for Two Pianos in D major (K.448), college students showed subsequent short-term (10-15 minutes) enhancement of spatial-temporal reasoning. These results received an enormous amount of attention in 1993 and were called the Mozart effect by the media.

2) Alzheimer patients [15-16] after listening to the Mozart Sonata had enhanced short-term spatial-temporal reasoning.

3) Exposure in epileptic patients, *even while in a coma,* to the Mozart Sonata reduced neuropathological spiking activity [17-19].

4) Long-term exposure to the Mozart Sonata enhanced learning of a maze by rats; the enhanced performance lasted more than four hours after the last exposure to music [20]. While teachers are not advised to give children such long-term exposure to any music, this study does open the possibility of some long-term enhancement simply from a *moderate* amount of listening to specific music over a long time period. (We are just now starting the first experiments ever done with young children to test this possibility of enormous interest.)

5) An EEG (surface brain wave) coherence study [21] gave evidence of a carryover from the Mozart Sonata listening condition to the subsequent spatial-temporal task in specific cortical regions. This provided the first neurophysiological evidence for the Mozart effect. The idea presented is that the Mozart Sonata "resonates" [3] with the innate columnar structure of the cortex.

6) Functional magnetic resonance imaging (fMRI) studies comparing cortical blood flow activation from the Mozart Sonata versus other music produced striking results [22]. In addition to expected fMRI activation in cortical regions associated with music, substantial activation was found in cortical regions important for spatial-temporal reasoning. Further fMRI studies (along with EEG studies) should not only prove extremely valuable in determining the neurophysiological basis for the Mozart effect, but in determining which other music might give similar enhancements in spatial-temporal reasoning.

- ***Direct tests of the trion model of higher-brain function: 7-8***

7)A consistency test of the trion model [3-9] and the Mountcastle [10-11] columnar spatial-temporal code for higher-brain function came with the demonstration of

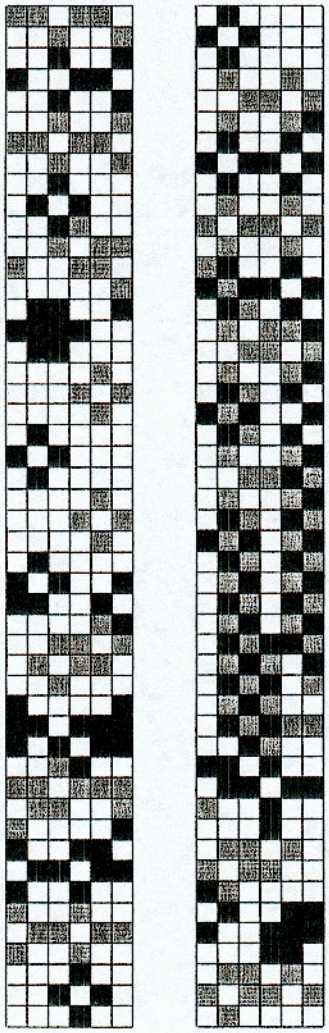

Figure1.

Figure1. Trion brain model probabilistic evolutions of the firing activity of a column of six idealized minicolumns or trions. This is an example of our idealized internal neural language of the brain's talking to itself. Each square in a given row represents the firing levels of a trion at that time step (row). Gray, light gray, and black represent above-average, average, and below-average firing levels, respectively. Time steps (rows) are ordered from top of the left column. The results were striking when these patterns were mapped onto music producing recognizable human styles [3].

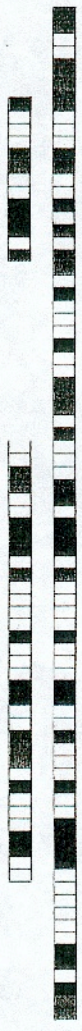

Figure 2. Trion-like firing patterns [24] of neurons from a real (primate) brain during a memory task showing symmetry properties as predicted [7-8].

Figure 2.

highly accurate mental rehearsals [23]. The temporal durations of mental rehearsals of pieces of music lasting up to a few minutes were extraordinarily reproducible by trained musicians from mental rehearsal to mental rehearsal, as measured by a stop watch.

8) Neurophysiological studies by Mark Bodner [24] confirmed, as predicted by the trion model, the presence of families of spatial-temporal firing patterns (Fig. 2) related by symmetries during memory tasks.

- ***Music training that enhances children's spatial-temporal reasoning and math learning: 9-11***

9) Preschool children [25] who received piano keyboard lessons for six months improved dramatically, with the effect's lasting for several days, on an age standardized spatial-temporal reasoning task.

10) STAR is an ingenious math software developed by Matthew Peterson. We contend that these nonverbal math games utilize spatial-temporal abilities built into our structured cortex. Inner-city 2nd-graders given piano keyboard training along with STAR training scored significantly higher [26] on proportional math and fractions than children given control training along with STAR. A special interactive version of STAR by Peterson may be found on the CD-ROM enclosed in Shaw [3].

11) Second-graders receiving our three-part method — piano keyboard training, STAR lessons, and lessons incorporating this ST approach into their regular language-based math curriculum — did as well on advanced math concepts as 4th-graders from a higher socioeconomic school not having our training [2]. These 2nd-graders also greatly enhanced their performance on nationwide standardized math tests (Stanford 9). Our three-component Music ST Math Program has an enormous potential for enabling children to learn difficult math concepts.

These 11 distinct and fundamental experiments are highly successful and extremely relevant to our general theme of "Music as a Window into Higher-brain Function." They are all supportive of the basic underlying trion model predictions that precipitated them and must be considered as an entire coherent body of knowledge. This fundamental scientific research continues — and, we are just at the beginning. It is as if we have found a vein of gold leading to the gold mine of understanding higher-brain function, and it is the trion [3-8] model that provides a road map to this understanding. We all know that the connections in young children's brains are rapidly being modified as a result of experience and learning. The crucial distinguishing concept of the trion model (as derived from the Mountcastle columnar principle of the cortex) is that the infant's brain starts with an innate, well-defined, and common internal neural language and grammar [9]. As we learn even more about this innate neural language from experiment and theory, we will be better able to help children learn to think and reason.

This summarizes the present key research milestones showing how music helps us understand how we think, reason, and create, and how music can enhance these higher-brain functions through our innate ST abilities. Now let us turn to our Music ST Math Program, which is an educational reality.

MUSIC ST MATH EDUCATION

The Music ST Math Program was begun in 1999 as a pilot study in schools and featured the three-part approach to learning previously described (music lessons, STAR lessons, and bridge lessons to language-based math). In the first year we concentrated on the advanced math concepts of proportional reasoning, fractions, and symmetry, which cannot be learned by rote. These concepts are not covered in any depth at the 2nd grade level, but are typically introduced in some detail in 4th and 5th grade and are continued through 8th grade. Our Advanced Math Concepts (AMC) [2] test assesses students' ability to apply their

understanding of proportional math, fractions, symmetry, graphs, and pre-algebra problems in a manner that does not make demands on language skills. The AMC problems also represent material covered in state standardized 3rd and 4th grade math tests, with the language simplified. In our one-year program, 1,283 2nd-graders in 12 schools had their math proficiency on difficult concepts increase by *an additional two years*. Our 2nd-graders scored the same on the AMC as 4th-graders (not in our program) in the same schools. Large gains have also been attained in the standardized Stanford 9 math performances. However, we have added several new major features to ensure even greater performance on standardized math exams [2].

We have now fully developed our 2nd and 3rd grade programs, along with a pilot 4th-grade program. We will have about 40 schools with over 8,000 2nd-, 3rd-, and

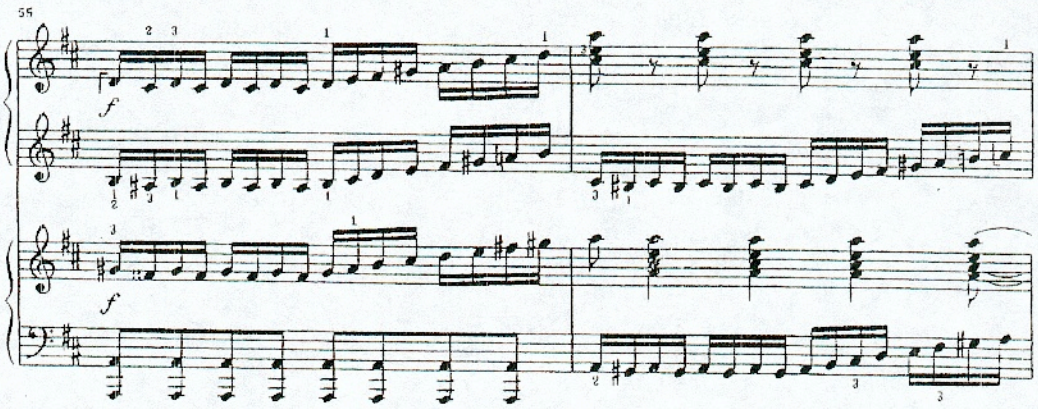

Figure 3. Mozart Sonata for Two Pianos in D Major (K.448), music score for measures 55 and 56 (1781).

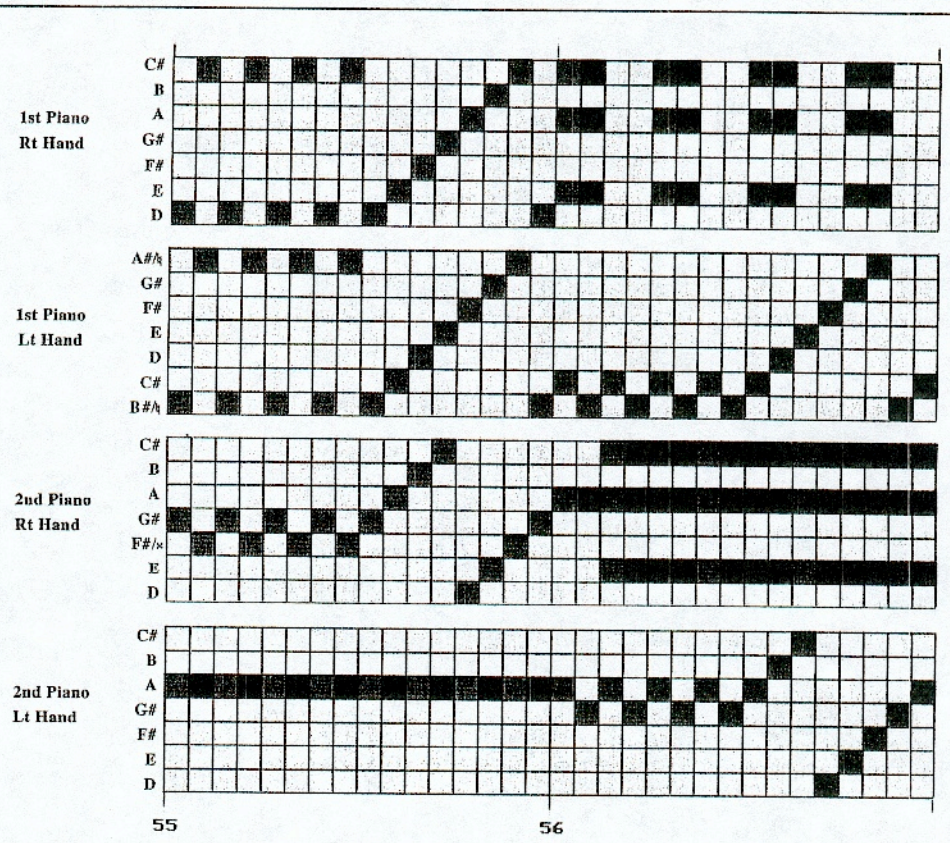

Figure 4. "Translation" or mapping of the two measures in Figure 3 (Mozart Sonata music score) onto trion-like patterns. Each square represents a sixteenth note. Dark gray means played, and black means held. The pitches wrap around; octaves are not shown, nor are grace notes or thirty-second notes. The visual display of symmetries is striking and dramatic (to the non-musician). This is especially evident when viewed in color on a computer and the movement of the displayed patterns is synched to the actual music performance.

4th-graders in our Music ST Math Program this coming school year, 2002-2003. Our goal in the next few years is to have a complete Music ST Math Program for grades K-6 available to schools around the country. Pilot programs, which support the music-math connection through music

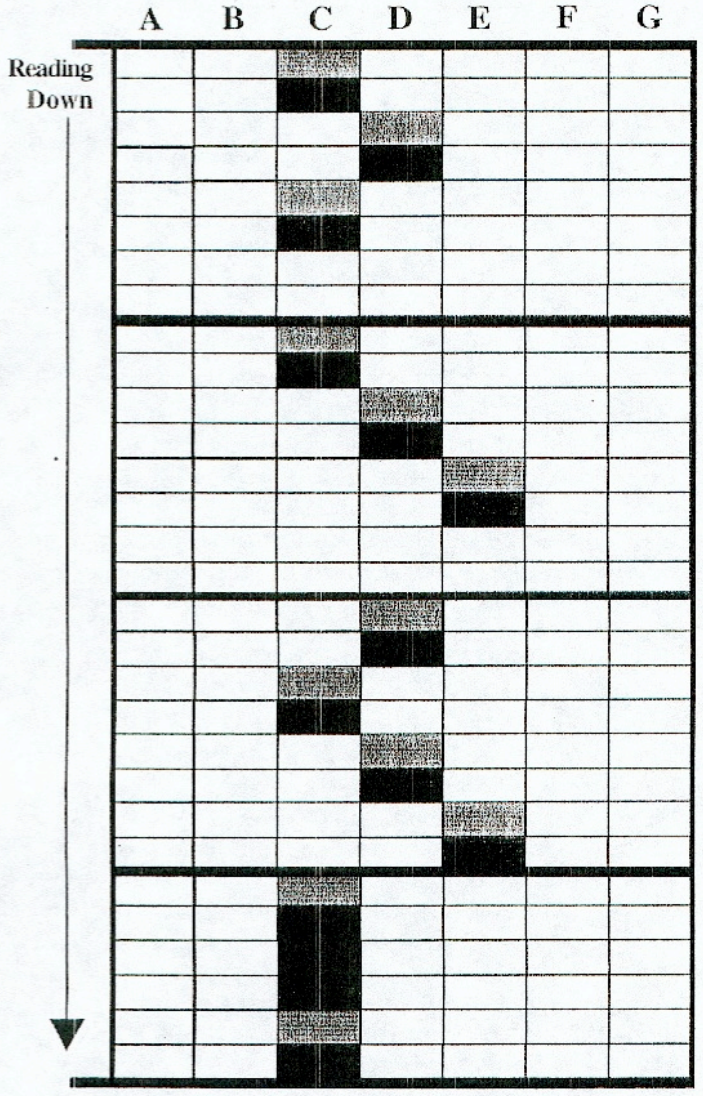

Figure 5. Trion-like music patterns for a simple piece. Contrasting with Figure 4, time runs from top to bottom so that this figure can be placed above a piano keyboard to be played by a young child with little music training. Also, each square is an eighth note. These simple trion-like music patterns have been displayed on a computer screen and synched to the music as played by the computer.

training and spatial-temporal math videogames, are now underway for preschool and special needs children. The Music ST Math program is intended to complement, not replace, the standard language-based math programs, and the music component of this program is being handled by trained music teachers and college music students. Clearly, excellent teachers and determined student are crucial in learning difficult math concepts; however, teachers and children must be given the appropriate tools.

The Music ST Math Program represents the beginning of a revolution in education which will allow children to learn difficult math and science concepts using their innate ST reasoning abilities. All children must be given the opportunity to learn to think mathematically and thus be able to compete in our high-tech world. Music training provides a crucial element in developing the innate neural "hardware" for these ST abilities.

THE MUSIC-MATH CONNECTION: WHY IT WORKS

Now we turn to the main new presentation. We intend to make the causal connection between music and math clear and intuitive. The reasoning steps are:

a. The trion model brain patterns, Figure 1, represent the internal neural language of the brain — one cortical column talking to another cortical column. These trion model memory patterns come in families related by symmetries and have the innate ability to perform spatial-temporal reasoning. Leng [4] mapped in a number of quite simple transformations of these patterns onto music through the computer and synthesizer and amazingly produced recognizable styles, including Baroque, Asian, folk music, and New Age (an MP3 file of her trion music is available upon request [27]). This led to the startling prediction that music would causally enhance spatial-temporal reasoning, so crucial in doing math.

b. The 11 innovative experiments summarized above then followed, all supporting this prediction. Of especial note here are:

i) The Mozart-effect experiments 1-6, as well as the piano keyboard training study 9,

demonstrated the causal effect of music's enhancement of spatial-temporal reasoning.

ii) The combination of music training with the spatial-temporal math video games established the music-math causal overlap 10.

iii) Neurophysiological studies 8 confirmed the presence of families of spatial-temporal firing patterns (Fig. 2) related by symmetries during a memory task, which are strikingly similar to the trion model patterns in Figure 1.

c. As a strong result of a. and b., we decided to take even more seriously the idea that the Mozart Sonata K. 448 could tell us something very significant about the symmetries of the brain. Envisioning that music could indeed provide a window into higher-brain function, we mapped the musical score (Fig. 3) of this Sonata onto patterns, as found both in the trion brain model (Fig. 1) and in actual brain patterns (Fig. 3). The result, Figure 4, (which is strikingly beautiful when shown in color) revealed symmetries in amazing clarity. This and other similar mappings of music onto trion-like patterns are now being examined qualitatively and quantitatively for insights into the neural language of higher-brain function.

d. The last piece in this chain came as a result of our realizing that the trion-like mappings c. (Fig. 4) could be used to help teach very young children to play simple music — utilizing spatial-temporal patterns, Figure 5, before employing the more "complicated" language of a musical score. We are in the process of testing the utility of this approach with preschool autistic children having limited language abilities.

To summarize, we have shown the strong qualitative and intuitive chain going from brain ST patterns (which are the basis of innate ST reasoning ability) to music and back to brain-like music patterns. Math reasoning uses the same visualization of ST patterns as exemplified in the STAR games [3]. Clearly then, the music-math connection is established. The full benefit of this music-math connection requires that math be taught using the ST approach as found in STAR. Figure 6 captures this message — the music-math ST connection allows children to develop their thinking and creativity [28].

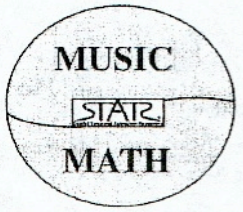

Figure 6. A descriptive logo showing the music-math connection exploiting the STAR math videogames [3] to optimize children's learning to think and create.

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