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Listening to Mozart enhances spatial-temporal reasoning: towards a neurophysiological basis

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Abstract

Motivated by predictions of a structured neuronal model of the cortex, we performed a behavioral experiment which showed that listening to a Mozart piano sonata produced significant short-term enhancement of spatial-temporal reasoning in college students. Here we present results from an experiment which replicates these findings, and shows that (i) 'repetitive' music does not enhance reasoning; (ii) a taped short story does not enhance reasoning; and (iii) short-term memory is not enhanced. We propose experiments designed to explore the neurophysiological bases of this causal enhancement of spatial-temporal reasoning by music, and begin to search for quantitative measures of further higher cognitive effects of music.

Keywords: EEG; Spatial-temporal neuronal pattern development; Trion model of cortex; Analytic reasoning; Creative reasoning; Music

A profound dilemma of historical origin is the similarity among such higher brain functions as music, mathematics and chess. There are many correlational [1] and anecdotal reports of such relationships. Using the trion model of the cortex [5, 11], Leng and Shaw [3] proposed a causal basis: the spatial-temporal firing pattern development by groups of neurons over large regions of the cortex for tens of seconds. Motivated by this, we performed a behavioral experiment [8] which found that students who listened to a Mozart piano sonata experienced significant subsequent enhancement on spatial-temporal tasks. Here we present results replicating these findings, and provide insights into their origin. We propose experiments to explore the neurophysiological bases of this causal enhancement by music, and begin to search for quantitative measures of further higher cognitive effects of music, in particular, creative (versus analytic) reasoning in chess.

The trion model [11] is a highly structured mathematical realization of the Mountcastle [6] organizational principle in which the cortical column is the basic neural network of the cortex, and is comprised of subunit minicolumns, the idealized trions (Fig. 1). A columnar network of trions has a large repertoire of inherent, quasi-stable, periodic spatial-temporal firing patterns which can be excited. They can be enhanced by small changes in connection strengths via a Hebb learning rule and probabilistically evolve from one to another in natural sequences (Fig. 2). These inherent patterns form the common neural language of the cortex [3]. The results were striking when evolutions of the patterns were mapped onto various pitches and instruments producing recognizable styles of music [3,4].

These inherent cortical firing patterns are related by specific symmetries [5]. For example, the 'diamond' pattern starting at time step 8 in Fig. 2A can be seen in several spatially rotated forms in Fig. 2B. The computation by symmetry operations among the inherent patterns may be a key property of higher brain function [5]. Although specific higher brain functions crucially depend on different cortical areas, many 'higher' cortical areas are involved in each higher brain function at some important level [3,7].

Music plays a very special role among higher brain functions as it is universally appreciated, even at birth [2,13]. Leng and Shaw [3] proposed that music is a 'pre-language' (with centers distinct from language centers in

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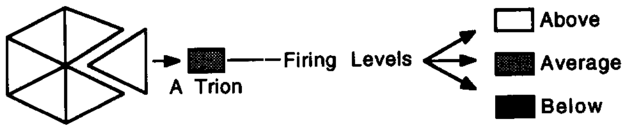

Fig. 1. Schematic representation of the structured Mountcastle [6] principle of cerebral cortex organization. The hexagon represents a cortical column. Each triangle is a minicolumn consisting of hundreds of neurons which encode the relevant parameter of the stimuli, such as bar orientation in the visual cortex. A minicolumn is identified with the idealized trion. The trion has three levels of firing activity.

the cortex), available at an early age, which can access these inherent firing patterns and enhance the cortex's ability to accomplish pattern development, thus improving other higher brain functions. Indeed, recent results have shown that early music training provides long-term enhancements of non-verbal cognitive abilities [9].

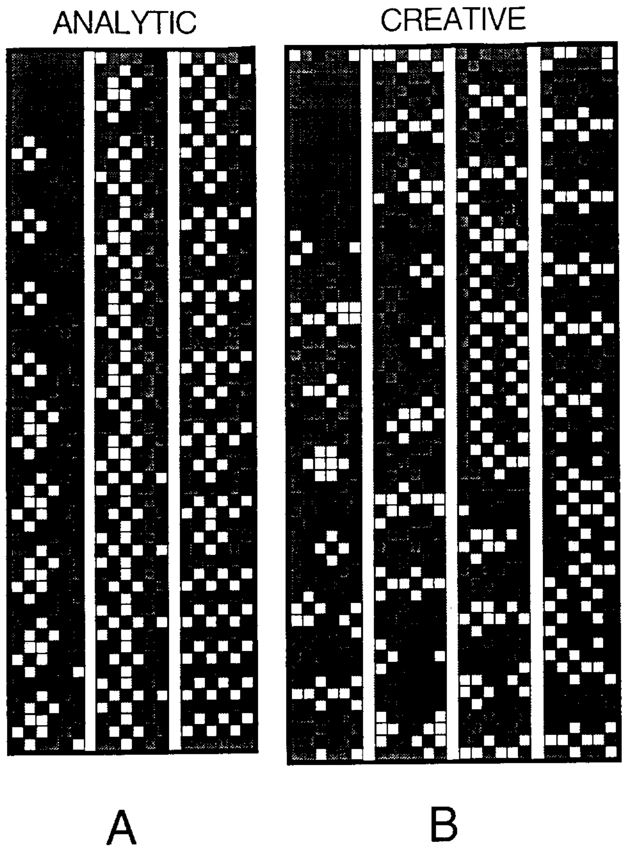

Fig. 2. Probabilistic evolutions from the trion model [3,11] of the firing activity of a columnar network of six trions giving examples of (A) the 'analytic' mode and (B) the 'creative' mode. Each square in a given row represents the firing levels of a trion (Fig. 1) at that time step. The time steps (rows) are consecutively ordered, beginning at the top of the column at the left and continuing from the bottom of that column to the top of the next column, etc. (A) There are seven different inherent firing patterns which cycle two or more times. This is an example of a sequential or analytic evolution of the inherent firing patterns and has high symmetry in the connections. (B) This is an example of a creative evolution, in that specific inherent firing patterns appear and reappear in forms related by symmetry operations [5]. This evolution has connections similar to that of (A) but with somewhat 'broken' symmetry and a synaptic fluctuation parameter which is somewhat larger, and presumably modifiable by the release of specific neuromodulators [3]

We performed a complementary experiment to determine if short-term causal enhancements of pattern development could be invoked by merely listening to music [7]. Thirty-six undergraduates listened to 10 min of Mozart's Sonata for Two Pianos, K. 448, and scored 8 to 9 points higher on the spatial IQ subtest of the Stanford-Binet Intelligence Scale [12] than after they listened to taped relaxation instructions or silence. This facilitation lasted only 10–15 min.

In the present study, 79 students participated for five consecutive days. We issued all students 16 Paper Folding and Cutting (PF&C) items on the first day of the experiment (Fig. 3), and then divided them into three groups with equivalent abilities. We also issued 16 short-term memory items. Of the three sub-tests in the spatial reasoning portion of Stanford-Binet's Intelligence Scale, we chose the PF&C task because it best fit our concept of spatial-temporal pattern development [3].

Each PF&C item was projected for 1 min. On days 2–4, the three groups were separated, and then participated as follows: On each day, the Silence group sat in silence for 10 min and were then tested with 16 new PF&C items; the Mozart group listened to 10 min of Mozart's Sonata K. 448 and were tested with the same 16 PF&C items as the Silence group. The Mixed group listened to 10 min of something different every day. On Day 2 they heard a minimalist work by Philip Glass; on Day 3 they heard an audio-taped story; and on Day 4 they heard a dance (trance) piece. They were tested on the same PF&C items as the other groups after each of these conditions.

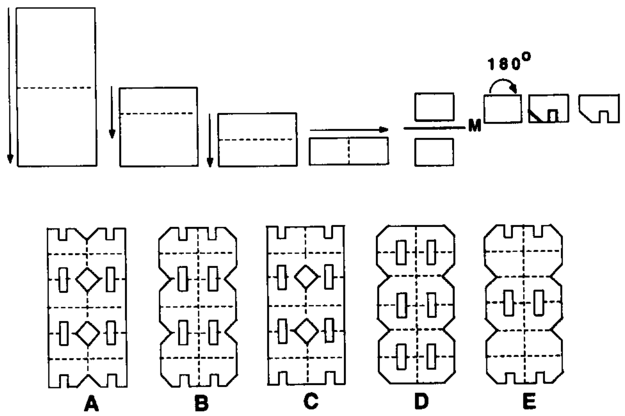

Fig. 3. PF&C task derived from the Stanford Binet's Intelligence Scale [12] with our inclusion of the symmetry operations of rotation and mirror reflection [5]. The items we presented to our subjects did not include these symmetry operations. It depicts a picture of a paper before it was folded and cut (top left figure). The dotted lines and straight arrows represent the location and direction of folds; the curved arrow and number indicate the direction and angle of rotation, and the heavy solid line marked with the letter 'M' gives the position of a mirror. The solid lines represent cuts. Subjects were to choose which of the five choices below show how the paper would look unfolded.

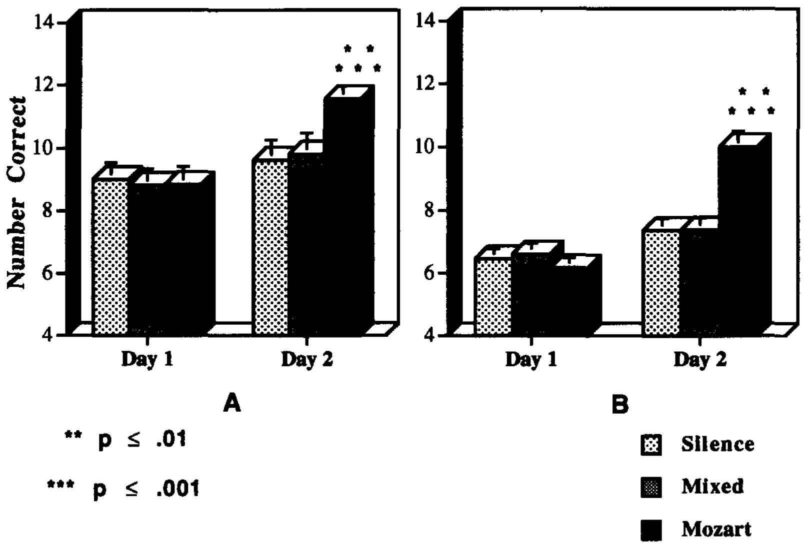

Fig. 4. (A) Mean number of PF&C items answered correctly out of 16 by the Silence, Mixed and Mozart groups for days 1–2. The Mozart group's improvement from day 1 to day 2 was significant ($P < 0.001$) and was significantly greater than the Silence and the Mixed groups on day 2 ($P < 0.01$). No other differences were significant. (B) Same as (A) only for those subjects scoring 8 or less on day 1. Note the dramatic increase from day 1 to day 2 of 62% for the Mozart group versus 14% for the Silence group and 11% for the Mixed group.

The results for Days 1 and 2 are shown in Fig. 4. A 3 (listening condition) by 2 (day) ANOVA revealed a significant day ($F_{(1,76)} = 31.75$, $P < 0.001$) effect and a significant day by condition interaction ($F_{(2,76)} = 6.38$, $P < 0.01$), as shown in Fig. 4A. Both are due to the large increase in correct scores for the Mozart group. Thus, in addition to reproducing the original findings [8] of the Mozart enhancement with respect to silence, this showed that repetitive music produced no enhancement of spatial-temporal reasoning.

Further, these enhancements were not only highly significant, but were quantitatively very large: Consider the subjects who got <9 correct on day 1 (Fig. 4B). Again, a 3 by 2 ANOVA revealed a significant day ($F_{(1,33)} = 17.14$, $P < 0.001$) effect and a significant day by condition interaction ($F_{(2,33)} = 5.12$, $P < 0.01$), again due to the large increase in correct scores for the Mozart group. The increases from day 1 to day 2 were 62% for the Mozart group versus 14% for the Silence group and 11% for the Mixed group.

The Mozart group attained the highest scores on days 3–5, but the Silence and Mozart groups did not differ significantly on days 3, 4 or 5. The Mixed group's scores remained significantly below those of the other groups. The immediate improvement of the Mozart group's scores was due to listening to the music, whereas the improvement of the Silence group's scores was probably the outcome of a learning curve. Including more difficult items (such as the symmetry operations shown in Fig. 3) should flatten this learning curve, remove the ceiling effect, and determine if the Mozart group's scores continue to improve relative to controls in subsequent days.

On day 5, the Mixed group was divided into two new groups with equal means and distributions, based on their day 1 memory items. The two groups were separated; one listened to the same Mozart Sonata, and the other group heard nothing. Immediately afterwards, we issued both groups the same 16 new memory items, which were difficult to memorize using a rhythmic pattern (e.g., M 9 ! B 2 ? N %). Each was presented for 5 s, and the students were to write down what they remembered in the correct order. As predicted, the Silence ($M = 7.85$) and the Mozart ($M = 7.54$) groups did not differ ($t = 0.18$, ns).

It is important to note that the PF&C task is not simply a spatial recognition task; it is a temporal series of spatial tasks. The model [3] predicts that such spatial-temporal patterns will be enhanced by the Mozart sonata. The introduction of symmetry operations (such as spatial rotation and/or mirror reflection) into the PF&C tasks (Fig. 3) should produce even larger effects.

We chose Mozart since he was composing at the age of four. Thus we expect that Mozart was exploiting the inherent repertoire of spatial-temporal firing patterns in the cortex. While one might explore the many possibilities with a large number of styles and composers, it would be more interesting to investigate the underlying neurophysiological bases using behavioral studies in conjunction with EEG investigations. Petsche and colleagues have shown [7] through EEG coherence analyses that not only is listening to music processed in many cortical areas, but that there are very large differences in how Mozart is processed versus Schönberg. We suggest a study of the coherence EEG patterns (and also EEG spatial-temporal patterns [10]) of subjects listening to the Mozart Sonata versus the two types of music which did not enhance spatial task performance. The EEG coherence patterns could be examined during spatial-temporal task performance and compared to the music listening EEG data. One might then predict whether a specific piece of music will generate the 'Mozart effect'.

Our proposed mechanisms for the enhancement of spatial reasoning by music include the following. (i) Listening to music helps 'organize' the cortical firing patterns so that they do not wash out for other pattern development functions, in particular, the right hemisphere processes of spatial-temporal task performance. (ii) Music acts as an 'exercise' for exciting and priming the common repertoire and sequential flow of the cortical firing patterns responsible for higher brain functions. (iii) The cortical symmetry operations among the inherent patterns (Fig. 2), are enhanced and facilitated by music.

These results encourage us to consider the implications of the two theoretical types of trion model evolutions (analytic and creative; Fig. 2). The cortical pattern evolutions necessary for the PF&C tasks may correspond to the analytic evolutions in Fig. 2A (sequential evolution of the inherent firing patterns) whereas the cortical pattern evolutions necessary for creative tasks correspond to the creative evolutions in Fig. 2B (in which specific inherent firing patterns appear and reappear in forms related by symmetry operations [5]). We suggest including master chess players in similar experimental designs. There are standard chess exercises and problems of the analytic variety and of the creative variety. Listening to the Mozart Sonata should produce short-term performance enhancement of the analytic chess exercises; somewhat different music would be necessary to enhance performance of the creative exercises. (All music excites both types of evolutions in different proportions, and all reasoning involves both the analytic and creative evolutions.) This experiment will not be trivial, and the significance of a successful result is enormous.

Perhaps the cortex's response to music is the 'Rosetta Stone' for the 'code' or internal language of higher brain function.

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