

KEY COMPONENTS OF THE MOZART EFFECT¹

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Summary.—The results of studies intended to replicate the enhancement of spatial-temporal reasoning following exposure to 10 min. of Mozart's Sonata for Two Pianos in D Major (K.448) have been varied. While some studies have replicated the effect, others have not. We suggest that researchers' diverse choice of dependent measures may account for these varied results. This paper provides a neurophysiological context for the enhancement and considers theoretical and experimental factors, including the choice of dependent measures, the presentation order of the conditions, the selection of the musical composition, and the inclusion of a distractor task, that may contribute to the various findings. More work is needed before practical applications can be derived.

Researchers have reported that college students who listened to the first ten minutes of Mozart's Sonata for Two Pianos in D Major (K.448) subsequently scored significantly higher on a spatial-temporal task than after listening to ten minutes of progressive relaxation instructions, silence, a story, Philip Glass' "Music With Changing Parts," or British-style trance music (16, 18, 20, 22, 23, 26, 28, 29). These findings, labeled the "Mozart Effect," have been reported in the popular press. Some researchers, however, have not reproduced these results (3, 17, 27, 33, 34), casting some doubt on the generalizability of the effect. Here we briefly propose some key components, both theoretical and experimental, which may account for the inconsistencies observed.

Early studies showing enhancement of spatial-temporal reasoning after exposure to Mozart were motivated by Shaw and his colleagues' "trion" model of the cortex (11, 14, 31, 32). The trion model is a highly structured mathematical realization of Mountcastle's (15) organizational principle for the cerebral cortex. Mountcastle proposed that the cortical column, the basic neural network of the cortex, can be excited into complex firing patterns which, in the trion model, are exploited in the performance of tasks requiring ability to recognize and classify physical similarities among objects—*spatial recognition tasks*. These neural firing patterns can be strengthened through small modifications to their connectivity strengths as indicated by Hebbian (9) learning principles, yielding a huge repertoire of inherent firing patterns which probabilistically develop into explicit temporal sequences last-

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ing tens of seconds and occurring over large portions of the cortex (11, 14, 31, 32).² The trion model proposes that these neural firing patterns allow for the performance of more complex spatial tasks—*spatial-temporal* tasks. In addition to requiring the recognition of object relations, spatial-temporal tasks require the ability to transform mental images in the absence of a physical model (23, 24, 25). Spatial-temporal reasoning is required for higher brain functions relevant to chess, mathematics, and engineering (11, 14, 31, 32). Music cognition, it was argued, should also require these temporal sequences of neural activity (11).

Although higher brain functions are typically associated with specific, localized regions of the cortex, most higher cognitive abilities draw upon a wide range of cortical areas (19, 30). Leng and Shaw (11) proposed that exposure to music might excite the cortical firing patterns used in spatial-temporal reasoning, thereby affecting cognitive ability in tasks that share the same neural code—spatial-temporal tasks. Tasks requiring spatial recognition, the researchers suggested, should not be affected by music exposure. Supporting this prediction, studies have indicated that preschool children who received piano keyboard instruction scored significantly higher on spatial-temporal tasks than children who received computer lessons or no lessons (5, 24, 25, 38). Consistent with predictions from the trion model (11), no significant improvements in spatial recognition tasks were observed (24, 25). The Mozart effect (lasting approximately 10 minutes) further supports the model, suggesting that listening to music helps to “organize” temporarily, the cortical firing patterns for spatial-temporal processes.

Further analysis of the data from Rauscher, Shaw, and Ky (22) supports the argument that listening to music affects only spatial-temporal tasks. The three tasks administered were taken from the Stanford-Binet Scale of Intelligence (36), with one task, the Paper Folding task, measuring spatial-temporal ability and two tasks (Pattern Analysis and Matrices) measuring other abilities. A 3 (Listening Condition: Music, Relaxation, Silence) by 3 (Task: Paper Folding, Pattern Analysis, Matrices) repeated-measures analysis of variance performed on the scaled scores reported in Rauscher, *et al.*'s study (22) yielded significant main effects for both Listening Condition and Task ($F_{2,22} = 6.82, p < .001$ and $F_{2,22} = 14.35, p < .001$, respectively). The students' scores on the Paper Folding task, a spatial-temporal task, were significantly higher after they listened to the Mozart Sonata than after they listened to instructions for relaxation or silence. Their scores on the Pattern Analysis and Matrices tasks, which are not spatial-temporal tasks, did not differ by listening condition (Table 1). These data suggest that exposure to music may affect

²A recent study with rhesus monkeys (1) provides neurophysiological evidence for these families of firing patterns.

TABLE 1
 PATTERN ANALYSIS, MATRICES, AND PAPER-FOLDING: MEANS AND STANDARD
 DEVIATIONS FOR CONDITIONS OF MUSIC, RELAXATION, AND SILENCE

Condition	Pattern Analysis		Matrices		Paper Folding	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Music	56.08	2.27	53.25	7.35	63.33*	2.19
Relaxation	55.17	2.44	52.17	4.67	56.50	5.76
Silence	54.25	3.44	52.60	5.96	55.17	5.97

* $p < .01$ (Scheffé).

spatial-temporal tasks, but not other spatial tasks, and support predictions from the trion model.

In addition to insights provided by the trion model regarding the types of spatial tasks that may be enhanced following music exposure, the cognitive literature also contributes useful information. Although there is disagreement as to how to best classify spatial abilities (7, 8, 10, 12, 13), most researchers agree that spatial ability is a multifaceted construct. For example, Eliot and Smith (8) propose two divisions of spatial tasks, with several subcategories of spatial tests existing within these divisions (7, 8, 35). Further complicating researchers' attempts to classify spatial tests is the observation that many spatial tests require a combination of spatial abilities (7, 8, 12, 13, 35). The diverse findings from studies exploring the Mozart effect suggest it is important for researchers to understand the differences between categories of spatial abilities because tasks testing the various subskills of the construct appear to respond differently to exposure to music.

Eliot and his colleagues' (7, 8, 35) taxonomy of spatial tasks includes three categories of tasks relevant to studies of the Mozart effect: paper-folding tasks, maze tasks, and paper-formboard tasks. Studies utilizing the former two tasks showed enhancement following exposure to Mozart's music (16, 18, 20, 22, 23, 26, 28, 29, 37) whereas a study utilizing the last task did not (3). The Backwards Digit Span task did not show enhancement following exposure to Mozart's music (33). And finally, two studies utilizing the Raven Progressive Matrices Test as a dependent measure have also not shown the effect (17, 34). Given that research suggests this test measures general analytic intelligence rather than spatial ability (2, 6, 7), these findings (17, 34) are not surprising. Accordingly, the Backwards Digit Span task and the matrices task are often not included in subclasses of spatial ability (7, 8, 10, 12, 35). We suggest that two components of spatial-temporal tasks—spatial imagery and the temporal ordering of spatial components—are essential for the Mozart effect. Studies have shown tasks which require these subskills of spatial ability, i.e., paper folding and maze tasks, were subject to enhancement following exposure to music (16, 18, 20, 22, 23, 26, 28, 29, 37),

whereas tasks which do not require these subskills, i.e., matrices tasks, which lack both components, the digit span task, which lacks spatial imagery, and the paper formboard task, which lacks temporal ordering, were not enhanced (3, 17, 33, 34). We propose that researchers studying the Mozart effect should consider the spatial components of mental imagery and temporal order when choosing dependent measures.

A further consideration for researchers studying the Mozart effect relates to the order of presentations of the listening and task conditions. Rauscher, Shaw, and Ky's initial study (22) utilized a two-part design in which participants were exposed to a listening condition immediately followed by the task. This design, rather than one incorporating a pretest before the listening condition, was employed to attenuate the effects of learning, which the researchers suspected could produce a ceiling effect that might obscure any enhancement produced by listening to the music, a suspicion that was later confirmed (23). A subsequent exploration of the pretest design yielded no differences between groups exposed to Mozart versus silence until a verbal distractor task was inserted between the pretest of the spatial-temporal task items and the listening treatment, at which point significant differences between the mean performance of students who listened to the Mozart sonata versus silence were present (18). These findings compliment those of Rideout and Taylor (29) who, using a sample of 32, reported enhancement following the insertion of progressive relaxation instructions between initial task administration and the listening condition.³ These studies suggest that practice effects may conceal the effects of listening to the music unless a delay period is introduced between the pretest and the listening condition during which subjects are cognitively engaged in a disparate activity.

The choice of musical composition may also influence cognitive performance. Digit span scores of subjects who listened to the Pachelbel Canon versus a Bartok piece (4) did not improve, although conclusions regarding spatial-temporal task performance cannot be drawn from this study due to the choice of task. Rideout, Dougherty, and Wernert (26) exposed subjects to the music of Mozart, a contemporary Yanni composition (which the authors propose is similar to the Mozart sonata in tempo, structure, melodic and harmonic consonance, and predictability), or instructions for progressive relaxation. Performance on a paper-folding task was significantly improved following exposure to both the Mozart and Yanni works. Enhanced spatial-temporal task performance, after hearing Schubert's Fantasia for Piano,

³In a study exploring the relationship between skin conductance and spatial task performance following exposure to the Mozart sonata, Rideout, Fairchild, and Urban (27) did not replicate these findings. It seems likely, however, that the small number of subjects ($n=12$) in the second study may account for the inconsistency in these two data sets.

4 Hands in F Minor (D940) (16) or Mozart's Piano Concerto No. 23 in A major (K.488) (37) was observed. However, paper-folding scores of subjects exposed to either minimalist or contemporary "trance" music showed no improvement (23). These varied findings suggest that complexly structured music, regardless of style or period, may enhance spatial-temporal task performance more readily than repetitious music.

Although the studies cited in this paper contribute useful information regarding the dynamics of the Mozart effect, they were not designed to indicate the potential neural mechanism responsible for the enhancement. A recent experiment performed with rats as subjects (21) suggested that neural processes are affected by exposure to music. Rats exposed *in utero* plus 60 days *postpartum* to the Mozart sonata (K.448) navigated a spatial maze faster and with fewer errors than did animals exposed to minimalist music, white noise, or silence. Histological work is currently underway to identify the potential neural processes involved in this enhancement. Further support of a neurophysiological basis for the Mozart effect may be found in a study employing coherence analyses of electroencephalogram (EEG) recordings taken from subjects listening to the Mozart sonata (in contrast to listening to a short story) and then performing a paper-folding task as analysis suggests enhanced synchrony between the neural activity in the right frontal and left temporoparietal cortical areas of the brain (30). Persistence of the EEG patterns after listening to the Mozart sonata was observed for over 12 minutes. This study suggests that behavioral experiments should explore the effects of a time delay inserted between the listening condition and the spatial-temporal measure. Similarly, Rideout and Laubach (28) found reliable correlations between differential EEG variables and changes in spatial task performance. Clearly, more research is needed to explore how spatial-temporal enhancement following music listening may be affected by neurophysiological factors. Knowledge of these factors is necessary before the effect can be fully exploited.

To conclude, we recommend that researchers exploring the Mozart effect carefully consider questions of task validity and experimental design. Other factors such as the subjects' age, musical training, preference for the exposure condition,⁴ and aptitude for the task may also play a role.⁵ Researchers investigating the influence of musicality on the effect should em-

⁴Nantais (16) found that subjects who preferred listening to a narrated story over Mozart Sonata K.448 scored higher on a paper-folding task. If one assumes that preference for an activity increases attentiveness, this suggests that attention may influence the Mozart effect. Rauscher, Shaw, and Ky (23), however, found no effect of their subjects' treatment preferences on spatial-task performance.

⁵Note, as detailed in Fig. 4B of Rauscher, Shaw, and Ky (2), that students who scored below the mean at baseline testing on Day 1 improved more than other students on Day 2, after listening to the Mozart sonata.

ploy a very precise operational definition of musical training to avoid problems of interpretation by subjects. Finally, it seems important to apply a conservative interpretation to the meaning of these data. Although it is likely that music-induced enhancement of spatial-temporal reasoning can increase over time (21, 23, 24), more work is needed before substantial practical applications can be derived.

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