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Window of Opportunity? Adolescence, Music, and Algebra

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Abstract

Research has suggested that musicians process music in the same cortical regions that adolescents process algebra. An early adolescence synaptogenesis might present a window of opportunity during middle school for music to create and strengthen enduring neural connections in those regions. Six school districts across Maryland provided scores from the 2006-2007 administrations of the Maryland Algebra/Data Analysis High School Assessment. Findings from a sample of 6,026 adolescents showed that students enrolled in formal instrumental or choral music instruction during middle school outperformed those who experienced neither of those modes of musical instruction. Significant mean differences in algebra achievement occurred between the instrumental and neither-instruction groups (13.34, $p < .001$) and between the choral and neither-instruction groups (3.82, $p < .001$). For African Americans, means significantly differed between the choral and neither-instruction groups (9.39, $p < .001$). The greatest mean difference between any two comparison groups occurred between the instrumental and neither-instruction groups of African Americans (18.87, $p < .001$).

Keywords

music, education/school, cognitive development, brain development, African Americans

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Tell me, I forget. Show me, I remember. Involve me, I understand.

Ancient Chinese Proverb

This ancient adage embodies the essence of brain-based learning. The more involved the student, the more readily sustained learning occurs. So it is with music: Instrumental music instruction, which makes use of synapses in virtually all cortical locations (Weinberger, 1998), impacts academic learning and achievement more so than voice or general music instruction. This study intended to explore specifically what influence, if any, formal music instruction (instrumental or voice) that is encountered during middle school might exert upon an adolescent's algebra achievement. Results supported the hypothesis that instrumental instruction affects algebra achievement the most, vis-à-vis choral instruction and other (or no) music instruction. This study suggested that the connection between music instruction and academic achievement might lie in cognitive neuroscience: the exposure to, the practice of, and the performance of music might strengthen the neural connections in those cortical areas of the brain used for algebra.

Statement of the Problem

The impact of federal legislation on today's American educational system merely marks the most recent response to public demand that the nation's high school graduates be functionally literate in today's global society. In response to No Child Left Behind (NCLB), each state must devise a system of assessments to determine whether high school graduates are competent in reading, mathematics, and science. As a result, many states are sacrificing education in the arts to afford more instructional time for the tested areas. In a national report for the Center on Education Policy, McMurrer (2008) found that 45% of the school district respondents had increased instructional time spent on mathematics in elementary schools, usually at the expense of other subjects or activities. Correspondingly, 16% of the total respondents had sacrificed time from art and music.

Despite this increase in mathematics instruction, the achievement gap on the national assessment of educational progress (NAEP) between 13-year-old African Americans and Whites has remained relatively unaffected (Lee & Bowen, 2006). That situation prompted this study to pursue whether the possible relationship between music and algebra achievement manifested itself similarly across different ethnic groups. If so, then perhaps learning music might help students to bridge that gap.

Background

Recent research has suggested that there is a relationship between instrumental music instruction and academic achievement as measured by state-mandated tests (Fitzpatrick, 2006; Kluball, 2000). However, much speculation exists concerning whether such achievement is the result of the (a) music instruction itself, (b) natural ability of the student who is predisposed to enroll in music courses, or (c) other secondary benefits of studying music that correlate with student success. Some have explained this symbiotic relationship as it relates to mathematics by suggesting that working with music and working with mathematics are closely related brain functions (Bahr & Christensen, 2000; Shaw, 2000). Schmithorst and Holland (2004) have suggested that music training affects the neural architecture that is used in mathematical processing. The author agrees with their theory and proffers that early adolescence is a critical phase of a child's educational career in forming this advantageous relationship between studying music and enhanced academic achievement, specifically in algebra.

The Musical and Mathematical Brain

Synaptogenesis

During early adolescence the brain experiences a synaptogenesis—a surge in the formation of new synapses—that peaks between the ages of 10 and 12 in both the prefrontal cortex and the parietal lobe (Giedd et al., 1999). This synaptogenesis is followed by a period of synaptic pruning. The pruning process strengthens the synaptic connections that are habitually used and eliminates weaker neural pathways; it is influenced by activities in which the adolescent participates (Giedd et al., 1999). The activities of musical and mathematical processing access those synapses in the prefrontal cortex and the parietal lobe (Schmithorst & Holland, 2003, 2004). Therefore, practicing music most likely strengthens the neural connections that also govern mathematical reasoning and computation. If that is the case, then formal music instruction during one's middle school years, in addition to fostering musical talent and music appreciation in their own rights, offers additional educational benefits for student achievement in other academic areas, particularly in mathematics and algebra.

Neuroplasticity

Formal music instruction may even alter the physical structure of the brain. Research has documented that musical training, especially before the age of seven years, alters the corpus callosum (Schlaug, Jäncke, Huang, Staiger, & Steinmetz, 1995). As the corpus callosum is one of the last areas in the brain to undergo myelination (Giedd et al., 1996), music instruction can also enhance callosal development during the early adolescent synaptogenesis. Indeed, Gaser and Schlaug (2003) determined that musicians showed structural changes in several brain areas, including the frontal, parietal, and temporal lobes, as well as the cerebellum. Therefore, it should be no surprise that music might enhance reasoning, motor functions, computation, auditory discernment, and coordination.

Common Networks for Music and Mathematics

Musical instruction stimulates changes in one's neural circuitry (Rauscher et al., 1997). It is likely that this modified circuitry affects both musical and mathematical abilities. More experienced musicians process the music they hear in the left hemisphere (Bever & Chiarello, 1974), the putative source for the language/analytic processes that are necessary for algebra. Specifically, Schmithorst and Holland (2003) found that both musicians and nonmusicians showed activity in the auditory cortex for processing melody and harmony, but only musicians showed activity in the inferior parietal lobe for both types of musical processing. Likewise, mathematical calculation accesses areas in the left hemisphere, particularly in the parietal lobe and perhaps more specifically in the left angular gyrus (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Gruber, Indefrey, Steinmetz, & Kleinschmidt, 2001; Menon et al., 2000; Rivera, Reiss, Eckert, & Menon, 2005). Furthermore, the angular gyrus is recognized for its involvement in reading (Horwitz, Rumsey, & Donohue, 1998), which would transfer to creating mental images of language and manipulating algebraic symbols. In fact, Bahr and Christensen (2000), in their study of adolescents, suggested that there is structural overlap between cortical areas involved in music and those involved in recognizing and manipulating symbols and patterns, both basic components of algebra.

Research has shown that the prefrontal cortex is also accessed for both musical and mathematical tasks. Functional MRI images have indicated activity in the prefrontal areas for increasingly complex mathematical computation (Menon et al., 2000), whereas other data have shown that the prefrontal cortex responds to tonal discrepancies or dissonant music in both musically experienced and nonexperienced participants (Blood, Zatorre, Bermudez, & Evans, 1999; Janata et al., 2002).

Specifically concerning algebra, Qin et al. (2004) confirmed that (a) the algebraic process of solving equations occurs in three cortical areas and (b) practice affects the efficiency of solving equations in adolescents. In a study of adolescents (aged 12-15), Qin et al. identified the (a) left prefrontal cortex, (b) left parietal lobe, and (c) left motor cortex as the cortical areas involved in solving algebraic equations. In the previous year, Qin et al. (2003) found that adults accessed those same cortical areas to solve equations. However, only the adolescents showed changes in the parietal area as a result of 5 days of practice, indicating that that cortical area was still developing in the adolescents but had already matured in the adults (Qin et al., 2004). For that reason, Qin et al. (2004) have suggested that adolescence is an appropriate time for students to learn algebra. This appropriate time coincides with the early adolescent synaptogenesis. That concurrence suggests that the increase of neuroplasticity in those cortical areas makes them more susceptible to practice during adolescence.

Significance of the Study

Eisner (1998) has claimed, "What is needed . . . is a theory that links experience in the arts with academic achievement" (p. 12). Much research has attempted to address that need. Numerous studies have focused on young children and the effect of instrumental training on general academic achievement or on spatial-temporal reasoning. This study attempted to extend the research base by considering the effect of music instruction on logical/analytical reasoning by asking the overarching question "What is the relationship between middle school formal music instruction and adolescent algebra achievement?" Southgate and Roscigno (2009) have explored other theories to link music and achievement, such as the sociological aspects of belonging to a group with common interests and goals. A review of the literature led this researcher to propose that an explanation for the connection lies in cognitive neuroscience. The findings led to the possibility of using music instruction to help narrow the minority achievement gap as documented on the Maryland Algebra/Data Analysis High School Assessment (HSA). Finally, very little research has determined whether choral instruction similarly affects academic achievement. This study hypothesized that voice instruction would affect scores to a lesser degree than instrumental instruction, such that when comparing the three musical groups in all subgroups, the instrumental students would achieve higher scores than choral students, who would achieve higher scores than students who received neither instrumental nor choral instruction.

Method

Study Design

This causal-comparative study explored (a) whether a relationship existed between the mode of music instruction received during Grades 6 through 8 and a student's subsequent performance in eighth-grade or ninth-grade introductory algebra, as measured by the Maryland Algebra/Data Analysis HSA; (b) whether that relationship remained evident when mathematical proficiency, as measured by the fifth-grade Maryland School Assessment (MSA), was controlled statistically; (c) whether that relationship manifested itself similarly within the two subgroups of African Americans and Whites; and (d) whether middle school music instruction modified ninth-grade algebra achievement. The last two cases were investigated because African Americans and ninth graders have historically experienced difficulty in passing the assessment.

The independent variable represented the type of music instruction the student received during middle school. The types of music instruction considered were (a) instrumental, (b) choral, or (c) neither of those modes. The dependent variable was algebra achievement, as measured by a student's score on HSA. The confounded variable was a student's mathematical proficiency in the Maryland Voluntary State Curriculum for mathematics, as measured by the fifth-grade mathematics portion of the MSA.

Sample

The sample consisted of 2006-2007 ninth-grade students (N = 6,026) in Maryland who had completed introductory algebra for the first time in either eighth grade or in ninth grade and had taken the Maryland Algebra/Data Analysis HSA at the completion of the course. Passing the HSAs is linked with receiving a diploma, so the students did not consider the test to be frivolous. The students formed three comparison groups: (a) students who received formal instrumental instruction during Grades 6, 7, and 8 (n = 1,952); (b) those who received choral instruction during those middle school years (n = 1,287); and (c) those who received neither instrumental instruction nor choral instruction during that same time (n = 2,787). An instrumental student was operationally defined as one designated by the local school district as having received music instruction in only band, orchestra, or a specific instrument for all 3 years during middle school. Similarly, a choral student was one designated by the school district as having received music instruction in only chorus during Grades 6, 7, and 8. A student was designated as one of the neither-instruction group if one had received neither instrumental nor choral instruction during all 3 years of middle school. Those neither-instruction students might have experienced a general music course or a combination of general music, visual arts, and/or other elective courses.

Instrumentation

Maryland Algebra/Data Analysis HSA, as of 2006, is the test used in Maryland to determine adequate yearly progress for high school mathematics in accordance with NCLB (Maryland State Department of Education [MSDE], 2008). The criterion-referenced assessment consists of 38 items covering topics in algebra, data analysis, and probability. Students must answer in various ways: There are 26 selected-response items, which include multiple choice selections; 6 student-produced response items, which require producing a numerical answer independent of any choices; 3 brief-constructed responses, in which a short, written explanation of the derived answer is required; and 3 extended-constructed responses, in which the student might need to (a) explain the process for reaching that answer or (b) justify the response using mathematical properties. The scale scores of the HSA, measured on an interval scale, range from 240 to 650. The state has designated a scale score of 412 as passing and scores of 412 to 449 as proficient; any score of 450 to 650 is advanced. The four subtests of the assessment and their percentages toward the total point value are (a) analyzing patterns and functions, 25%; (b) modeling real-world situations, 32%; (c) collecting, organizing, and analyzing data, 22%; and (d) using data to make predictions, 21% (MSDE, 2005).

Since 2003, the MSA is the instrument that determines adequate yearly progress for Grades 3 through 8 in accordance with NCLB. The MSA is a criterion-referenced test that measures how well students have grasped the learning outcomes of the Maryland Voluntary State Curriculum. In 2003, the assessment consisted of items from CTB/McGrawHill's TerraNova survey and was augmented with items specific to Maryland learning standards (MSDE, 2003). Fifth-grade MSA scores represented the last standardized assessment in mathematics before these students entered middle school and began the formal music instruction that concerned this study; the scores were collected to control statistically one's previous mathematical proficiency in the Maryland Learning Outcomes. The range of scores for this 2003 assessment was 200 to 620, with 392 representing a passing score. Since then, the MSA scores have been recalibrated so that the lowest obtainable scale score (240) and highest obtainable scale score (650) parallel the HSA scores.

Validity

To ensure the validity of the Maryland Algebra/Data Analysis HSA, the content specialists and assessment personnel from MSDE collaborated with CTB/McGraw-Hill and Educational Testing Service (ETS) to develop specifications for each item and a training manual for test item writers. Using explicit guidelines, Maryland mathematics educators and ETS personnel created test items for the algebra assessment in alignment with the Maryland Core Learning Goals. Versions passed between MSDE and ETS for repeated revisions. As an important concluding step in the process, algebra educators of every level from all geographical areas of the state examined each item for bias and ensured the test items matched the indicators for both functions/algebra and data analysis/probability (MSDE, 2005). This lengthy collaborative process between Maryland educators and ETS content specialists contributed to the content validity of the instrument, by ensuring the alignment of test items with content-specific indicators for the Maryland Core Learning Goals. Presently, all questions for the assessment (except field test items) originate from a bank of items, each of which addresses a Maryland educational standard for algebra or data analysis content (MSDE, 2005).

Reliability

Cronbach's alpha, a measure of internal consistency, was calculated to estimate reliability for the Maryland Algebra/Data Analysis HSA. Cronbach's alpha estimates the probability that a student would receive a similar score on a different form of the test (MSDE, 2005). In 2005, the alpha was .93 for the primary forms of the May administration, .93 for the Makeup Form X, and .90 for the Makeup Form Y; in January 2005, Cronbach's alpha was .91 for the Primary Forms A and B and .89 for the makeup forms (MSDE, 2005).

Procedure

Data were collected from six school districts across the five geographical regions of Maryland (central, eastern, western, southern, and capital). The following data, stripped of any identifying information, were collected for each student: (a) the mathematics score on the 2003 fifth-grade MSA; (b) the type of music instruction received during Grades 6, 7, and 8 (instrumental, choral, or neither of those); (c) the total score on the Maryland Algebra/Data Analysis HSA; and (d) the score for each of the four subtests of the assessment. However, the subtest scores were not included in the results because the subtest raw scores were less statistically reliable than the total scale scores.

ANOVA, ANCOVA, and pairwise comparisons (Bonferroni adjustment) investigated the means and adjusted means of the three musical groups, utilizing SPSS (version 15.0 for Windows). That entire analytical process was repeated for the subgroups of African Americans and Whites to explore whether formal music instruction might help Maryland students narrow the achievement gap that has been documented on the HSA. A third complete analytical process explored whether the same relationship between formal music instruction and algebra achievement existed for ninth-grade musical groups because ninth graders have also experienced difficulty in achieving proficiency on the HSA.

Results

Total Sample

For the total sample of eighth graders and ninth graders combined, ANOVA indicated that formal music instruction encountered during the middle school years resulted in a significant difference among the three treatments, $F(2, 6023) = 133.12$, $p < .001$, classical $\eta^2 = .04$. Table 1 details the pertinent results for the three musical groups.

The statistically significant mean differences indicated that formal instrumental instruction impacted algebra scores the most; choral instruction also affected scores but to a lesser extent. The mean difference between the instrumental and neither-instruction groups was 13.34 ($p < .001$); the mean difference between the choral and neither-instruction groups was 3.82 ($p < .001$).

Given the chicken-and-egg quality of innate ability or learned proficiency with one's participation in instrumental or choral music, the next consideration was whether the instrumental students exhibited more mathematical proficiency than the others before the middle school music instruction. An examination of the 2003 MSA mean scores indicated that instrumental students did score the highest of the three groups ($M = 407.52$, $SD = 33.72$) but showed the choral group had the lowest mean score ($M = 393.87$, $SD = 36.30$), which barely exceeded the passing score of 392. The neither-instruction

Table 1. Maryland Algebra/Data Analysis High School Assessment: 2006-2007 Mean Performance Results for Students in Total Sample

Group	*n*	*M*	*SD*	Minimum	Maximum	Percentage passing
Instrumental	1,952	442.71	24.22	323	650	90.62
Choral	1,287	433.19	26.81	240	501	81.51
Neither-instruction	2,787	429.37	30.63	240	533	75.03

group's mean score was between those of the other two groups ($M = 394.79$, $SD = 44.09$), but those scores indicated more variability.

Results of ANCOVA indicated that, after eliminating the variance from previous MSA performance and error, middle school formal music instruction remained a significant source of the variance in HSA scores, $F(2, 6022) = 71.67$, $p < .001$, partial $\eta^2 = .02$. Again, the adjusted mean difference between the instrumental group and the neither-instruction group was the greatest (7.51, $p < .001$). The difference between the adjusted means of the choral students and neither-instruction group was less but still significant (4.24, $p < .001$). The adjusted mean difference between the instrumental and choral groups was also significant (3.27, $p < .001$).

White and African American Subgroups

Both subgroups of Whites and African Americans exhibited the same pattern as that of the total sample. As Table 2 illustrates, the instrumental mean score was the greatest within each subgroup.

ANOVA indicated that formal music instruction translated to a statistically significant difference in HSA mean scores for each subgroup, $F_{AA}(2, 1247) = 45.73$, $p < .001$ and $F_W(2, 4773) = 78.51$, $p < .001$. Classical η^2 showed that music instruction accounted for 7%, a medium effect size, of the variance in African American scores and 3%, a small effect size, of the variance in White scores.

For African Americans, the instrumental minimum score was 100 points greater than that of the neither-instruction group; the maximum scores of the three groups were virtually equivalent. The mean difference between each pair of musical groups was statistically significant for African American students, with the greatest difference occurring between the instrumental group

Table 2. Maryland Algebra/Data Analysis High School Assessment: 2006-2007 Mean Performance for Students in Subgroups of Total Sample

	White (non-Hispanic)			African American		
Group	*n*	*M*	*SD*	*n*	*M*	*SD*
Instrumental	1,622	445.94	22.46	330	426.83	26.26
Choral	1,020	437.34	24.83	267	417.36	28.21
Neither-instruction	2,134	435.92	27.14	653	407.97	31.63

and the neither-instruction group (18.87, $p < .001$); the mean difference between the choral group and the neither-instruction group was also significant (9.39, $p < .001$). Instrumental students enjoyed the highest percentage of passing students (73.33%), which was 11% more than that of the choral group (62.17%) and 26% more than that of the neither-instruction group (47.17%). Conspicuously, the MSA means of all three musical groups represented failing scores on the fifth-grade mathematics assessment. However, after the middle school music instruction, the instrumental and vocal groups represented passing HSA scores, whereas the mean of the group receiving neither instruction did not.

For Whites, the instrumental minimum score was 83 points greater than the lowest obtainable scale score of 240; at least one student in each of the other two groups scored 240. One instrumental student achieved the highest obtainable scale score of 650. Straying from the pattern, the neither-instruction maximum score (533) exceeded the choral maximum (501). The instrumental group's mean score was 8.60 greater than that of the choral group and 10.02 greater than that of the group with neither instruction ($p < .001$ for both). The mean difference between the choral and neither-instruction group was not statistically significant ($p = .42$). The means of all three musical groups represented passing scores on the MSA, with the choral students forming the group with the lowest mean score. However, after the middle school instruction, the choral group's mean was greater than that of the group with neither instruction. The percentage of those passing exhibited the same hierarchical pattern as that of the other subgroup: 94.14% for instrumental students, 86.57% for choral students, and 83.55% for those students receiving neither instruction.

Results of ANCOVA indicated that the effect of formal music instruction remained significant after accounting for the variance due to both previous

MSA performance and error, $F_{AA}(2, 1246) = 21.17$, $p < .001$ and $F_{W}(2, 4772) = 47.66$, $p < .001$. However, the effect size was small, with music accounting for 3% of the variance in scores for African Americans and 2% of the variance in scores for Whites. Subsequent pairwise comparisons indicated that the differences of the adjusted means were statistically significant for all combinations of groups.

For African Americans, the difference between the instrumental and neither-instruction group adjusted mean scores was the greatest (10.56, $p < .001$). The adjusted mean difference between choral and neither-instruction groups was significant (5.78, $p = .003$), but the adjusted mean difference between instrumental and choral students was not (4.78, $p = .049$).

For Whites, the greatest adjusted mean difference also occurred between the instrumental and neither-instruction groups (6.38, $p < .001$). The adjusted mean differences between both choral and neither-instruction (3.35, $p < .001$) and between instrumental and choral groups were also statistically significant (3.04, $p < .001$).

Ninth-Grade Students

Historically, students encountering introductory algebra for the first time in ninth grade have also experienced difficulty in achieving proficiency on the HSA, as "accelerated" students generally enroll in introductory algebra before ninth grade. The subgroup of ninth-grade students was considered to explore whether middle school music instruction affected "average" students. An examination of ninth-grade HSA performance revealed a similar pattern to that of the total sample, suggesting that the relationship between formal music instruction and algebra achievement remained evident for both subgroups of ninth-grade students. Table 3 illustrates the relevant results for ninth graders.

Results of ANOVA suggested that the effect of middle school formal music instruction persisted after another year of schooling, $F(2, 2894) = 50.32$, $p < .001$, $\eta^2 = .03$. However, this research did not pursue whether students continued their formal music studies in ninth grade, as the increased number of options for electives in high school generally preclude students who are not musically inclined from further music instruction. The instrumental students again scored the highest mean of the three groups, with the instrumental group's mean score 9.33 greater than that of the choral group and 13.57 greater than the mean score of the neither-instruction group ($p < .001$ for both).

Table 3. 2007 Maryland Algebra/Data Analysis High School Assessment Mean Performance for Students in Ninth Grade

Group	*n*	*M*	*SD*	Minimum	Maximum	Percentage passing
African American						
Instrumental	140	418.22	28.86	340	479	56.43
Choral	150	409.13	30.28	246	465	49.33
Neither-instruction	442	399.46	31.46	240	468	35.07
White						
Instrumental	519	436.29	22.89	323	493	88.05
Choral	442	427.86	27.05	240	491	76.24
Neither-instruction	1,204	426.01	27.47	240	533	73.42
Total						
Instrumental	659	432.45	25.36	323	493	81.34
Choral	592	423.11	29.04	240	491	69.42
Neither-instruction	1,646	418.88	30.91	240	533	63.12

Results of ANCOVA indicated that the variance due to music instruction was significant, $F(2, 2893) = 42.70$, $p < .001$, partial $\eta^2 = .03$. The instrumental group's adjusted mean score was 6.00 greater than that of the choral group and 10.28 greater than that of the neither-instruction group ($p < .001$ for both), suggesting that formal music instruction in middle school might benefit the ninth grader in demonstrating proficiency in algebra on the HSA.

As in the total sample, the mean of African American ninth-grade instrumental students exceeded that of the group receiving neither instruction by more than 18 points. For African American ninth graders, the means of both the choral and neither-instruction groups represented failing scores. Still, the choral group mean was almost 10 points greater than that of the neither-instruction group. Further analysis suggested that the music instruction affected ninth-grade African Americans more than it did the eighth graders, $F_8(2, 515) = 5.55$, $p < .005$ and $F_9(2, 729) = 21.48$, $p < .001$, with music accounting for 5% of the variability in ninth-grade scores.

The variance in the scores attributable to music instruction was significant for both subgroups: $F_{AA}(2, 729) = 21.48$, $p < .001$, $\eta^2 = .06$ and $F_W(2, 2162) = 27.97$, $p < .001$, $\eta^2 = .02$. For African Americans, the largest mean difference occurred between the instrumental and neither-instruction groups (18.76, $p < .001$). ANCOVA revealed that middle school music instruction significantly influenced HSA mean scores for both ninth-grade subgroups:

$F_{AA}(2, 728) = 14.29, p < .001$, partial $\eta^2 = .04$ and $F_W(2, 2161) = 27.91, p < .001$, partial $\eta^2 = .02$.

Discussion

One might never determine with certainty the nature of the relationship between formal music instruction and general academic achievement, but the results of this study substantiate the hypothesis that middle school music instruction impacts one's ability to achieve in algebra.

However, the extent of that connection between music and algebra achievement most likely lies in a combination of factors. One must ask, "Do instrumental and choral students necessarily possess certain traits that are also helpful in learning algebra?" Perhaps students who are more academically talented, self-disciplined, or industrious possess a natural affinity for studying music and therefore enroll in formal music courses. For example, music students have attributed their achievement to internal roots of ability and effort (Asmus, 1986). Certainly, that intrinsic motivation would transfer to other academic areas. Moreover, music teachers assert that studying music fosters creativity, diverse thinking, and problem-solving skills (Moran, 2004). Those abilities should result in enhancing one's aptitude for learning algebra. Bahr and Christensen (2000) have noted that learning to read music involves manipulating patterns and symbols, which are fundamental concepts in algebra.

Perhaps, too, there is some external educational benefit that is embedded within the music instruction. Both Piaget (Inhelder & Piaget, 1958) and Vygotsky (2004) believed that social interaction is a crucial requisite for learning, and adolescents are socially sensitive. Possibly interaction among peers in a codependent relationship such as band, orchestra, or chorus also plays a role in facilitating cooperation and learning. Moreover, the repeated practice that is required for music might incline the music student to persevere in learning algebra.

Albeit all these possibilities might well be true, this study proposes that middle school music instruction enhances academic achievement, specifically in algebra, because it takes place during a time in which a proliferation of new synapses occurs in the developing brain. This synaptogenesis, peaking between the ages of 10 and 12, coincides with the transition from Piaget's concrete operational stage to formal operational stage of thinking (Inhelder & Piaget, 1958). Accordingly, studies (Giedd et al., 1999; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999) have indicated that this synaptogenesis provides a neurobiological basis for the change in adolescent thinking that both Piaget and Vygotsky had proposed decades earlier. This study corroborates the opinion that these new synapses are formed and strengthened, at least in part, by activities—music in this case—that are undertaken during early adolescence (Giedd et al., 1999). The ninth-grade results suggest these connections survive the synaptic pruning process that follows. Therefore, middle school might present a window of opportunity for learning music. This window could explain the lack of improved academic performance of piano students as sixth graders in a longitudinal study (Costa-Giomi, 1999). That would also explain the findings that participating in music exerted a positive effect on the academic achievement of adolescents, especially when that participation had occurred recently (Southgate & Roscigno, 2009).

Research has indicated that musicians analyze the music they hear in the left hemisphere, whereas nonmusicians hear the music as a whole in the right hemisphere (Bever & Chiarello, 1974). Musicians also access the left fusiform gyrus and the left prefrontal cortex to perform mental math (Schmithorst & Holland, 2004). These findings substantiate the reasoning that musicians process music in the same cortical regions as adolescents process algebra, specifically the (a) left prefrontal cortex, (b) left parietal lobe, and (c) left motor cortex (Qin et al., 2004). If music and mathematics utilize the same general cortical areas, then the practice of one should influence the other. That could explain why the music instruction seems to enhance achievement in spite of one's innate ability or learned mathematical proficiency, as evidenced in this study for choral students and African Americans.

That is, the choral group had the lowest mean score on the fifth-grade MSA, but after receiving middle school choral instruction, they scored a higher mean on the algebra assessment than those students in the group that received neither instruction. When MSA scores were statistically controlled, the adjusted mean difference between the same two groups was slightly greater. For White students, the mean difference between these groups was statistically significant only when the MSA scores were controlled. This observation implies that students of higher ability do not necessarily enroll in choral instruction, but choosing choral studies rather than no formal music courses can influence algebra achievement.

For African Americans, the means of all three musical groups represented failing scores on the fifth-grade MSA. However, after the middle school years, the means of both the instrumental and vocal groups represented passing HSA scores, whereas the mean of the group receiving neither instruction did not. For the total sample and ninth graders, the instrumental music group's mean exceeded that of the group receiving neither instruction by more than 18 points. Furthermore, the lowest HSA score for the instrumental group was 100 points more than that of the group with neither instruction. In addition, the mean difference between the choral and neither-instruction groups for White ninth graders was quite small, suggesting that the significant mean difference for those two musical groups in the ninth-grade sample was attributable mainly to the African American scores.

These results suggest that formal music instruction affects the algebra achievement of African American students to a greater degree than that of White students. Further analysis indicated that the music exerted more effect on the ninth-grade students than on the accelerated eighth graders. Why is that so? To reflect on the possible responses to that question, one should consider the underlying causes of the documented minority achievement gap. Among their explanations for the achievement gap, African American students themselves have cited the following: (a) lack of motivation, (b) lack of effort, (c) peer pressure, (d) teacher ability or concern, (e) low expectations of parents, and (f) attitude of students toward the test as being frivolous (Taylor, 2002). If music education affects neuroplasticity, then one's ability to achieve would surmount such outside pressures. Therefore, offering music education in middle school might present an alternative strategy for narrowing the achievement gap that is evidenced on the HSA.

Perhaps the defining relationship between music education and academic achievement will never be determined. As results from this study indicate, pairwise differences between scores are less when previous mathematical proficiency is controlled statistically, as one would expect. However, the adjusted mean differences remain significant, corroborating that music affects the structure of the brain and enhances learning regardless of innate cognitive ability (Rauscher, Robinson, & Jens, 1998). As Nelson, Thomas, and de Haan (2006) have noted, one's "experience shapes these neural connections and interactions (but always within the constraints imposed by genetics)" (p. 4). One would expect that intelligence intensifies the effect of formal music instruction but does not necessarily govern it. However, results from this study indicate that music instruction exerts a greater influence on students who are not accelerated, as evidenced by the results of the ninth-grade versus eighth-grade African Americans. However, one does not expect that formal music instruction alone can completely compensate for little mathematical ability.

One would hope the results of this study help to strengthen the tenuous thread linking musical training with academic achievement. However, this study is not without limitations. First, the usual tests utilized in SPSS implied that the distributions of HSA scores were not normal. However, these tests are not always reliable for large samples, and graphical representations of the data illustrated that the distributions did approach normality. The leptokurtic curves of the instrumental and choral groups were attributed to the outliers; approximately 2% of each musical group were outliers. Second, the Levene Test implied the variances of the groups might not have been homogeneous. However, ANOVA is a moderately robust test despite minor violations of its assumptions (Maxwell & Delaney, 1990; Sheskin, 2000). Sheskin (2000) has recommended using a more stringent alpha level when the assumptions are violated. For that reason, an alpha level of .005 was stipulated for each significant comparison mentioned here. In spite of these statistical limitations, the mean differences mentioned here speak for themselves.

Another limiting consideration is that these results may not apply to students in other states, due to different state-defined testing standards. However, it is suggested that researchers in other demographic areas explore whether music instruction affects adolescent algebra or other academic achievement. Finally, due to the nature of educational choice in music, a true experimental situation was not feasible. This causal-comparative study did not hope to resolve the chicken-and-egg quandary concerning music instruction and algebra achievement; instead, it intended to spur further research into the investigation of the impact of music on other academic learning.

Future studies offer promise of exploring the neurocognitive basis for the effect of music on achievement. Schlaug, Norton, Overy, and Winner (2005) have undertaken a longitudinal study in an attempt to ascertain whether the structural and functional differences in the brains of musicians occur as a result of a genetic predisposition to learn music or as a result of the musical training. Their preliminary published results show that suggestions of neuroplasticity are beginning in the instrumental group but not in the control group. Perhaps the final results of Schlaug et al. will offer definitive answers and provide increased insight into the impact of music instruction on neuroplasticity. Ideally, that study and others similar to that of Schmithorst and Holland (2004), which investigated musicians performing mathematical operations, should solidify the link between music instruction and algebra achievement.

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