

THE RELATION BETWEEN MUSIC AND PHONOLOGICAL PROCESSING IN NORMAL-READING CHILDREN AND CHILDREN WITH DYSLEXIA

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PAST RESEARCH HAS SHOWN THAT MUSIC and language skills are related in normal-reading children as well as in children with dyslexia. In both an ongoing longitudinal study with normal-reading children and a pilot study with children with dyslexia, we found a strong relationship between musical discrimination abilities and language-related skills. In normal-reading children, musical discrimination predicted phonological and reading skills (Studies 1 and 2). These relationships were stronger in children with music training than in control children without music training. In children with dyslexia, musical discrimination predicted phonological skills, which in turn predicted reading abilities (Study 3). Furthermore, normal-reading children with music training surpassed both normal-reading controls and children with dyslexia in melodic discrimination. Controls also outperformed children with dyslexia (Study 4). Taken together, these findings suggest that a music intervention that strengthens the basic auditory music perception skills of children with dyslexia may also remediate some of their language deficits.

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DESPITE DECADES OF RESEARCH INTO THE causes and remediation of developmental dyslexia, hundreds of thousands of children with dyslexia in the United States and many more in the rest of the world remain impaired in their literacy skills, resulting in severe difficulties at school and disadvantages throughout adulthood (Lyon, 1998). Developmental

dyslexia is defined as a specific learning disability that is neurobiological in origin (Lyon, Shaywitz, & Shaywitz, 2003). The disorder has been traditionally characterized as the presence of reading difficulties in combination with normal or superior intelligence, motivation, and schooling.

Considerable research shows the core deficit of these children to be phonological (Breier et al., 2001; Bryant & Bradley, 1985; Snowling, 1987): children with dyslexia have difficulty segmenting words into their phonemes (e.g., *pat* into /p/, /a/, and /t/) as well as into their syllables (e.g., *toothbrush* into *tooth* and *brush*), and distinguishing related phonemes (e.g., /p/ and /b/). There is mounting evidence that underlying this phonological deficit is a general deficit in the processing of dynamic, rapidly changing auditory information (Farmer & Klein, 1995; Tallal, 2004), regardless of whether this processing involves speech (Tallal & Stark, 1981) or nonspeech sounds (Breier et al., 2001; Tallal & Piercy, 1973). fMRI studies have also shown that rapid temporal information processing occurs in the same left-hemisphere brain regions irrespective of whether the processing involves speech or nonspeech information (Joanisse & Gati, 2003; Tallal & Gaab, 2006; Zaehle, Wustenberg, Meyer, & Jancke, 2004).

There is also some contradictory evidence suggesting that underlying dyslexia is a deficit specific to the processing of speech sounds rather than a general auditory processing problem (Mody, Studdert-Kennedy, & Brady, 1997; for a review see Studdert-Kennedy & Mody, 1995). However, Tallal and Gaab (2006) argued that these studies did not use children with a clear diagnosis of dyslexia, nor did they use paradigms that were parallel to those used to demonstrate a general auditory deficit. New methods aimed at resolving the debate between the general auditory deficit and speech-specific deficit hypotheses include prospective longitudinal studies of genetically at-risk populations. Benasich and Tallal (2002), for instance, found (using both behavioral and ERP measures) that auditory processing in infancy is a strong predictor of language outcomes at three years of age.

A few preliminary studies have explored the possibility that training in perceiving and producing music may also improve the ability to process rapidly changing acoustic

cues found in speech sounds (Trainor, Shahin, & Roberts, 2003). Furthermore, Gaab et al. (2005) showed that participants with music training seem to have an enhanced ability to process rapid spectro-temporal acoustic cues and use different neural networks for the processing of these cues. There are several reasons why music training might help remediate some of the reading difficulties associated with developmental dyslexia: (1) practice in listening to and producing the sound changes in music could provide a form of engaging, pleasurable auditory training that leads to improved processing of speech sounds; (2) the practice of singing (putting words to music) may help children segment words into their syllables (e.g., note the exaggerated segmentation of the word “gently” when it is sung, rather than spoken, in “Row row row your boat, *gent-ly* down the stream”); and (3) reading music notation requires the same decoding of symbols (moving from left to right, pattern recognition, mapping of sounds to symbols) used by written language, and thus may very well generalize to the development of both language processing and reading skills.

The relationship between music learning and language-related skills has been shown in normal-reading individuals. In adults, perception of pitch contour in speech correlates with phonological and reading skills (Foxton, Talcott, Witton, Brace, McIntyre, & Griffiths, 2003). In seven- to eleven-year-old children, tonal memory and chord analysis correlate with reading level (Barwick, Valentine, West, & Wilding, 1989). In four- and five-year-olds, pitch processing correlates with phonemic awareness (Anvari, Trainor, Woodside, & Levy, 2002; Lamb & Gregory, 1993) and reading skills (Lamb & Gregory, 1993). Douglas and Willats (1994) found that in eight-year-olds, rhythm (though not pitch) processing correlates with reading and spelling skills. Furthermore, in a meta-analysis of studies examining the correlation between music learning and reading, Butzlaff (2000) found a positive and significant effect size of $r = .17$.

Music learning and language-related skills are also related in children with dyslexia. Three studies have demonstrated that children with dyslexia or reading-based learning disorders are impaired in rhythm perception (Atterbury, 1985; Overy, 2003; Wolff, 2002); one study found that they are also impaired in pitch perception (Atterbury, 1985). Children with dyslexia also have difficulty learning to read music notation (Ganschow, Lloyd-Jones, & Miles, 1994; Jaarsma, Ruijsenaars, & Van den Broeck, 1998), a problem that cannot be explained by a rapid auditory processing deficit alone. The music notation reading deficit suggests that children with dyslexia also have difficulties in auditory discrimination, segmentation of sounds, as

well as grouping sounds into phrases and mapping of sounds to visual symbols. It is possible that while learning to read music notation, children with dyslexia can also be taught to transfer strategies to the reading and processing of language, thereby making it easier for them to master the arbitrary associations between visual symbols (i.e., letters) and auditory objects (i.e., phonemes) of more complex sound structures (i.e., words).

Results of experimental studies using a music intervention to enhance reading skills in normal-reading children have been mixed. Furthermore, although some studies have reported positive effects of music training on reading skills, no study thus far has shown that a music intervention can be as, or more effective than, for instance, nonmusical auditory training. Future research will be needed to compare music training with other types of intervention in order to assess its efficacy.

In the first study to demonstrate that music learning could improve reading, Hurwitz, Wolff, Bortnick, and Kokas (1975) reported that seven months of Kodály music training (40 minutes daily) improved reading skills in seven-year-old children. Similarly, Moritz (2007) found that six months of Kodály music instruction (45 minutes daily) improved rhyming and phoneme segmentation subskills in a group of five-year-olds. Butzlaff (2000) conducted a second meta-analysis, this time only on the experimental studies testing the effect of music training on reading skills and reported no significant overall positive effect size. However, the fact that three studies (Douglas & Willats, 1994; Fetzer, 1994; Kelley, 1981) out of the six included in the meta-analysis yielded positive effect sizes indicates that further research is needed.

Two experimental studies demonstrated that a music intervention can improve some of the language skills of children with dyslexia. Overy (2003) found that one year of singing-based music lessons (three 20-minute lessons/week) caused six-year-old children at both mild and strong risks for dyslexia to improve on phonological and spelling tasks, but not on reading. In a second study, Overy (2003) found that a similar 15-week intervention with eight-year-olds produced significant improvements in rhythm copying, rapid auditory processing, phonological skills, and spelling, but there was still no significant gain in reading. A significant improvement in reading ability may require a longer, more intensive intervention allowing for more progress on the underlying skills of auditory processing and phonological skills.

The goal of the studies reported here was to test the general hypothesis that musical abilities and language-related skills are related in both normal-reading children and children with dyslexia. Study 1 tests the hypothesis that skill in phonological processing and

music (pitch and rhythm) processing correlate, and that this relation should be stronger in children with music training. Study 2 tests the hypothesis that skill in reading abilities and music (pitch and rhythm) correlate, and once again that this relationship should be stronger in children with music training. Study 3 tests the hypothesis that the deficits in phonological processing and reading found in children with dyslexia should predict deficits in music (pitch and rhythm) processing. Study 4 again tested the hypothesis of Study 3, this time comparing children with dyslexia against normal-reading children (with and without music training).

Study 1

Study 1 examined the relationship between musical discrimination abilities and phonological skills in normal-reading children, some of whom were receiving instrumental music training, over the course of 31 months. We expected absolute scores at baseline and change scores from baseline to follow up to be significantly correlated. We also hypothesized that the relationship between improvement in musical discrimination and phonological skills would be stronger in the group of children who received music training (music group) than in the group of children without music training (control group).

Method

PARTICIPANTS

Forty-four children (mean age at baseline = 6.52 years, $SD = 0.78$) already enrolled in an ongoing longitudinal study (Forgeard et al., 2007; Norton, Winner, Cronin, Overy, Lee, & Schlaug, 2005) completed a phonemic awareness test both at baseline and after 31 months. Thirty-two children formed the music group (mean age at baseline = 6.72 years, $SD = 0.78$). Unlike the sample used in Forgeard et al. (2007), where only children with fewer than 26 weeks of instrumental training at baseline were included, all children tested in our current longitudinal study were included in the present analysis. The children with music training therefore already had an average of 35 weeks of instrumental training ($SD = 52$) at baseline, and 161 weeks after 31 months ($SD = 54$). Twelve children formed the control group (mean age at baseline = 6 years, $SD = 0.51$); these children did not receive any instrumental music lessons.

MATERIALS AND PROCEDURES

Children's socioeconomic status (SES) was determined by having parents report their highest level of education

on a questionnaire and responses were scored on a six-point scale (for more details, see Norton et al., 2005). To control for verbal IQ, we administered the Vocabulary subtest of either the WPPSI-III (for children under six) or the WISC-III (Wechsler, 1991, 2002); we used scaled scores in our data analysis in order to have comparable vocabulary scores for all children. Phonemic awareness was assessed using the Auditory Analysis Test (Rosner & Simon, 1971). Musical discrimination abilities were assessed using the tonal/melodic and rhythmic tasks of both Gordon's Primary Measures of Music Audiation (PMMA, for children between kindergarten and third grade) (Gordon, 1986) and of a custom designed discrimination task from our laboratory (Norton et al., 2005; Overy et al., 2004). In the PMMA, children listened to 40 pairs of tone sequences and 40 pairs of rhythms and made a same/different judgment by circling a pair of same or different faces on the answer sheet. In our own discrimination task, children listened to 16 pairs of five-tone sequences and 16 pairs of five-impulse rhythm sequences and indicated whether they were same or different by pressing a same/different button. In contrast to the PMMA, our task consisted of stimuli that were identical in duration and used the sound of an actual music instrument (rather than sine-wave tones).

Results and Discussion

A series of multiple regressions controlling for age, verbal IQ, and SES showed that, at baseline, phonemic awareness (as measured by the Auditory Analysis test) correlated significantly with Gordon's tonal and rhythm subtests, as well as with our own Melodic Discrimination task (all $p < .01$). Our Rhythmic Discrimination task did not significantly predict phonemic awareness. Improvement in phonemic awareness from baseline to 31 months (as measured by change scores) was predicted by improvement on Gordon's tonal subtest (partial $r^2 = .09$, $p = .06$) and by improvement on our own Melodic Discrimination task (partial $r^2 = .16$, $p = .02$). Improvement in phonemic awareness was not predicted either by improvement in Gordon's rhythm subtest or in our Rhythmic Discrimination task (both $p > .1$). Improvement in phonemic awareness was predicted by improvement on the Melodic Discrimination task for the music group (zero-order $r = .54$, partial $r^2 = .18$, $p = .04$, $n = 27$) but not for the control group (zero-order $r = -.24$, partial $r^2 = .02$, $p = .76$, $n = 10$) (see Figure 1 in color plate section). Using Fisher's r to z transformations, we found that the zero-order correlation coefficients of the music and control groups differed significantly ($Z = 1.98$, $p = .05$). Partial correlation coefficients did not differ significantly

(even though they are quite different), probably because of the small size of the control group.

The findings of Study 1 showed that there is a relationship between phonological skills and pitch processing in normal-reading children, and that this relationship is stronger in children receiving instrumental lessons (and therefore receiving more auditory music training) than in a control group. In Study 2, a small exploratory study, we tested whether a similar relationship exists between reading abilities and pitch processing.

Study 2

Method

PARTICIPANTS

Ten children (mean age = 6.27 years, $SD = 0.68$) enrolled in an ongoing longitudinal study completed a test of reading ability at baseline and after 14 months. Because the reading test was introduced into our longitudinal study after the study was underway, only a small subset of children completed this test at baseline. To complicate matters, some children left the study before completing their post 31 months testing cycle. We were therefore only able to look at their improvement after 14 months. Six children (mean age = 6.38 years, $SD = 0.70$) formed the music group. They had received an average of 20 weeks of instrumental training ($SD = 29$) at baseline, and 86 weeks ($SD = 37$) after 14 months. Four children (mean age = 6.11 years, $SD = 0.71$) formed the control group.

MATERIALS AND PROCEDURES

In addition to the battery of tests used in Study 1, children received three subtests of the Woodcock Language Proficiency Battery (1991): Picture-Vocabulary (which assesses verbal skills independent of reading), Letter-Word Identification (in which children read real words out loud), and Word Attack (in which children read nonsense words out loud).

Results and Discussion

A one-way ANOVA showed no difference between the two groups in the six-point SES scale, $F(1, 8) = 3.95, p = .08$. An additional preliminary ANCOVA (covarying age) showed no difference between groups on the Woodcock Picture-Vocabulary subtest (using raw scores) ($p > .1$).

A series of multiple regressions controlling for age, verbal IQ, and SES was again performed. At baseline,

Word Attack raw scores were predicted by our own Melodic and Rhythmic Discrimination tasks ($p < .05$). The Letter-Word Identification subtest was not predicted by any music outcomes (all $p > .1$). Improvement on Word Attack (as measured by change scores from baseline to 14 months) was predicted by improvement on our Melodic (partial $r^2 = .64, p = .03$) and Rhythmic (partial $r^2 = .78, p < .01$) tasks, but not by Gordon's tonal or rhythm subtests (see Figure 2 in color plate section). We did not test for Letter-Word Identification, as this task was not predicted by any music outcome at baseline. Improvement in Word Attack was predicted (near-significantly) by our Rhythmic Discrimination task in our music group (zero-order $r = .36$, partial $r^2 = .99, p = .07, n = 6$) (see Figure 3 in color plate section). Improvement in Word Attack was not predicted by improvement in our Melodic Discrimination task: the variance accounted for was very large but not significant, probably due to our small sample size (zero-order $r = .89$, partial $r^2 = .95, p = .15, n = 6$). Because there were only four children in the control group, all factors could not be entered simultaneously in a single multiple regression analysis. A series of linear regressions showed that neither verbal IQ, SES, age, interval (time between testing sessions), nor change in our Melodic and Rhythmic Discrimination tasks predicted Word Attack improvement (all $p > .05$). There was no difference between the zero-order correlation coefficients of the music and control groups (for either task), once again probably because of our small sample size. However, a repeated-measures ANCOVA (covarying SES and Interval) revealed that children with music training improved significantly more than controls on Word Attack, Wilks' Lambda = .173, $F(1, 6) = 28.63, p < .01$ (see Figure 4 in color plate section). In addition to SES, interval was covaried out of precaution, because the children with music training ($M = 14.76$ months) had a somewhat longer interval than controls ($M = 11.64$ months).

The results of Study 2 showed that auditory musical skills are strongly related to reading abilities in normal-reading children. Furthermore, within-group regressions showed that this relationship was especially strong in the music group (in which music skills accounted for almost all of the variance in Word Attack). Children in the music group also improved significantly more on Word Attack than children in the control group over the course of a little more than a year. In Study 3, we tested the relationship between auditory musical and language abilities in children with dyslexia.

Study 3

Method

PARTICIPANTS

Children diagnosed with dyslexia were recruited from two specialized schools in the Boston area. Prior to admission, both schools require a diagnosis of dyslexia made by a licensed clinical/school psychologist and based on combined results of either the Neuropsychological or Psychoeducational test battery and WISC scores. In addition, children accepted to these schools must be of above average intelligence, and with reading skills that are one to three years below grade level. In general, the children in our study who had been diagnosed with dyslexia performed within age-appropriate levels on the subtests of the WISC, but performed significantly lower on reading tests and tests of phonological awareness/phonological skill. Thirty-one children (mean age = 10.05 years, $SD = 1.00$) who carried the diagnosis of dyslexia participated in this study.

MATERIALS AND PROCEDURES

In addition to the battery of tests already described, we administered Raven's Progressive Matrices (Raven, 1976a, 1976b) to control for nonverbal intelligence. Gordon's Intermediate Measures of Music Audiation (IMMA; for children between first and sixth grades) (Gordon, 1986) was administered instead of the PMMA.

Results and Discussion

The 31 children scored on average at the 21st percentile on both the tonal ($SD = 24.25$) and the rhythm ($SD = 24.14$) subtests of Gordon's IMMA. A paired t -test revealed no significant difference between subtests ($p = .98$). In contrast, children scored above average on both Raven's Colored ($M = 66$ th percentile, $SD = 20.85$) and Standard ($M = 61$ st percentile, $SD = 29.17$) Progressive Matrices.

We conducted a series of regression analyses partialing out age and SES. Phonemic awareness was predicted by Gordon's tonal ($p = .07$, partial $r^2 = .12$) and rhythm ($p = .10$, partial $r^2 = .10$) subtests, as well as by our own Melodic (partial $r^2 = .19$, $p = .02$) and Rhythmic (partial $r^2 = .11$, $p = .08$) Discrimination tasks. Furthermore, phonemic awareness predicted performance on Woodcock Word Attack (partial $r^2 = .54$, $p < .01$) and Letter-Word Identification (partial $r^2 = .27$, $p < .01$). Reading outcomes, however, were not predicted by musical discrimination skills.

The children with dyslexia in Study 3 showed deficits in both melodic and rhythmic discrimination abilities, using the norms of Gordon's IMMA as our control measure. In addition, phonemic awareness was predicted by musical discrimination skills, and in turn phonemic awareness predicted reading abilities. However, melodic and rhythmic discrimination skills did not directly and significantly predict reading abilities.

Contrary to our expectations, not all children recruited for this study scored below the 50th percentile on the Woodcock subtests. Therefore, in Study 4 we used only children whose test scores met the criteria for developmental dyslexia (below the 50th percentile on reading scores, above the 50th percentile in nonverbal IQ). We were able to compare a subset of five children with dyslexia to ten normal-reading children.

Study 4

Method

PARTICIPANTS

In Study 4 we compared five children diagnosed with dyslexia with ten normal-reading children from our ongoing study. The five children with dyslexia all scored below the 50th percentile on the Woodcock Word Attack subtest ($M = 28$ th percentile, $SD = 8.11$) and above the 50th percentile on both Raven's Colored ($M = 65$ th percentile, $SD = 13.69$) and Standard ($M = 86$ th percentile, $SD = 10.25$) Progressive Matrices. We subdivided the ten normal-reading children into a music group and a control group: five had been playing a music instrument for one or more years and five had never played an instrument. The five children with dyslexia also never received any instrumental music training. Children in the three groups were matched on gender, age, and nonverbal reasoning abilities as measured by Raven's Progressive Matrices. Our sample size remained small because few children in our ongoing study had ages that matched (+ or - five months) those of children in our pilot study.

MATERIALS AND PROCEDURES

Children received the same battery of tests administered in Study 3: the SES questionnaire, the Woodcock Picture-Vocabulary, Letter-Word Identification and Word Attack subtests, the Auditory Analysis Test, Raven's Progressive Matrices, and our own Melodic/Rhythmic Discrimination tasks. Gordon's scores were not compared because children in our longitudinal study were given the PMMA while children in our pilot study were given the IMMA.

Results and Discussion

LANGUAGE-RELATED OUTCOMES

Preliminary ANOVAs revealed no significant differences between groups in age, SES, Picture-Vocabulary and Raven's scores (all $p > .1$). As expected, one-way ANCOVAs (covarying age) revealed significant differences between groups on the Woodcock Letter-Word Identification, $F(2, 11) = 9.66, p < .01$, and Word Attack subtests, $F(2, 11) = 34.92, p < .01$, as well as in phonemic awareness, $F(2, 11) = 9.95, p < .01$. The control and music groups had significantly higher scores than the group of children with dyslexia on all three tests (all $p < .01$, using Bonferroni corrections). There was no significant difference between the two groups of normal-reading children.

MUSIC OUTCOMES

An additional one-way ANOVA revealed that groups differed significantly in our Melodic Discrimination task, $F(2, 12) = 34.84, p < .01$. Posthoc tests revealed that children with music training surpassed both controls and children with dyslexia; in addition, controls surpassed children with dyslexia (all $p < .01$). Children with dyslexia ($M = 65.00$) performed lower than $M - 2SD$ of the control group ($M = 77.50, SD = 3.42$).

Groups also differed significantly on our Rhythmic Discrimination task, $F(2, 12) = 8.17, p < .01$. Both the music ($p = .03$) and control ($p < .01$) normal-reading children outperformed children with dyslexia. However, they did not differ significantly from each other. Once again, children with dyslexia ($M = 56.25$) performed lower than $M - 2SD$ of the control group ($M = 83.75, SD = 7.13$) (see Figure 5 in color plate section). The results of Study 4 showed that children with dyslexia performed significantly worse than normal-reading children (with or without music training) in melodic and rhythmic discrimination. Furthermore, children with music training also surpassed the control group on melodic discrimination abilities.

General Discussion

Taken together, the results of Studies 1 through 4 confirm that a strong relationship exists between auditory musical discrimination abilities and language-related skills in children. In normal-reading children, melodic discrimination abilities predicted both phonological and reading skills but rhythmic discrimination abilities only predicted reading skills. These relationships were stronger in children with music training than in controls, suggesting that music training may help develop

language-related skills. However, the fact that children in the music group had already received an average of 35 weeks (Study 1) and 20 weeks (Study 2) of music training before the baseline assessments limits the conclusions that we can draw from our results, since the relationship between auditory musical discrimination abilities, phonological, and reading skills could potentially have existed prior to music training.

In children with dyslexia, auditory musical discrimination abilities predicted phonemic awareness, which in turn predicted reading abilities. Our findings provided additional support to the existing claims that music training enhances phonemic awareness (Overy, 2003) and that phonemic awareness predicts reading abilities (Ehri, Nunes, Willows, Schuster, Yaghoubzadeh, & Shanahan, 2001; Lonigan, Burgess, & Anthony, 2000). Furthermore, our results also suggested that children with dyslexia appear to have deficits in both pitch and rhythm processing as they consistently scored below average on the two subtests of both the Gordon's Intermediate Measures of Music Audiation and our own Melodic/Rhythmic Discrimination task, despite the fact that their performance was similar to normal-reading children on Raven's Progressive Matrices (all participants performed above the 50th percentile). Thus, the effects cannot be explained by a nonverbal IQ difference. These results raise the interesting possibility that children with dyslexia may have a more global form of musical impairment than has been appreciated in the literature so far. This might also indicate that language impairments may not be the mirror image of musical impairments (see also Peretz & Hyde, 2003) since language-impaired individuals may not only have timing deficits (Tallal, Miller, & Fitch, 1993; Zatorre, Belin, & Penhune, 2002). The literature on musical deficits in dyslexia as well as our own findings point to a more widespread musical impairment in children with dyslexia. This is also consistent with the view of shared resources or significant overlap between language and music (Patel, 2003).

Our findings suggest that a music intervention aimed at improving both pitch and rhythm auditory processing may be successful at remediating some of the behavioral and neural correlates of developmental dyslexia. More research is needed to investigate whether music training can help children with dyslexia enhance their phonological and reading abilities, and if so, the kind of music intervention that would be the most effective. However, the results of the present studies support our hope that a general instrumental or singing-based music intervention may help children with language-based learning disabilities recover normal language and music skills.

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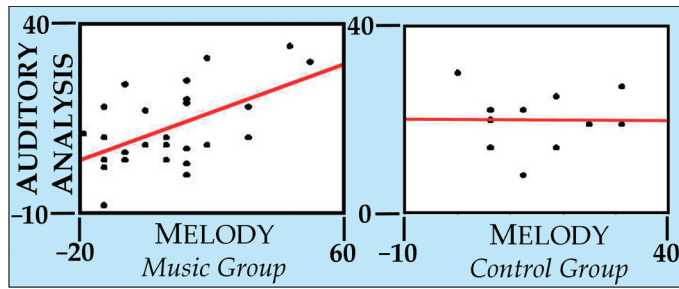
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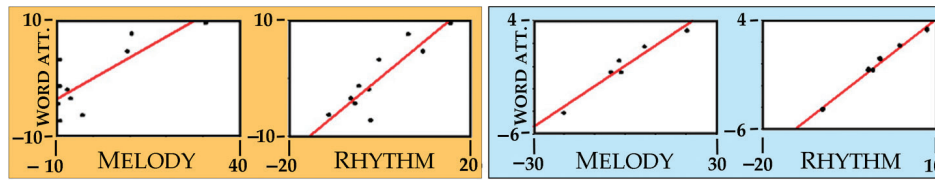
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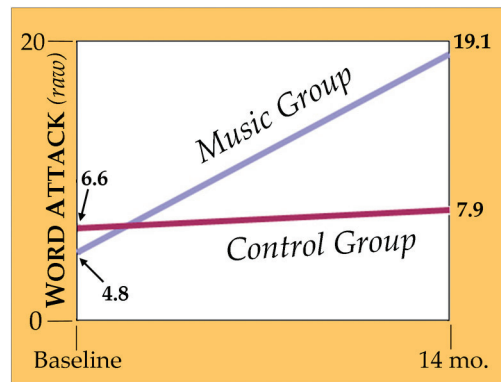
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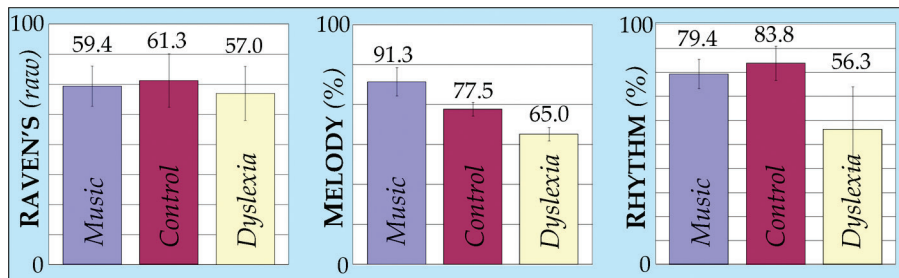
MARIE FORGEARD, GOTTFRIED SCHLAUG, ANDREA NORTON, CAMILLA ROSAM, UDITA LYENGAR, AND ELLEN WINNER, FIGURE 1. Correlations (using absolute change) between Auditory Analysis and the Melodic Discrimination task, by group (Study 1).



MARIE FORGEARD, GOTTFRIED SCHLAUG, ANDREA NORTON, CAMILLA ROSAM, UDITA LYENGAR, AND ELLEN WINNER, FIGURE 2 AND 3. Partial correlations (using absolute change) between Word Attack and the Melodic/Rhythmic Discrimination task, with all participants (left) and within children with music training (right) (Study 2).



MARIE FORGEARD, GOTTFRIED SCHLAUG, ANDREA NORTON, CAMILLA ROSAM, UDITA LYENGAR, AND ELLEN WINNER, FIGURE 4. Group \times Time interaction (Study 2).



MARIE FORGEARD, GOTTFRIED SCHLAUG, ANDREA NORTON, CAMILLA ROSAM, UDITA LYENGAR, AND ELLEN WINNER, FIGURE 5. Performance on Raven's Progressive Matrices and the Melodic/Rhythmic Discrimination tasks, by group (Study 4).