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'MusiMath' and 'Academic Music' – Two music-based intervention programs for fractions learning in fourth grade students

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Abstract

Music and mathematics require abstract thinking and using symbolic notations. Controversy exists regarding transfer from musical training to math achievements. The current study examined the effect of two integrated intervention programs representing holistic versus acoustic approaches, on fraction knowledge. Three classes of fourth graders attended 12 lessons on fractions: One class attended the 'MusiMath' holistic program (n = 30) focusing on rhythm within the melody. Another class attended the 'Academic Music' acoustic program (Courey et al., Educ Stud Math 81:251, 2012) (n = 25) which uses rhythm only. The third class received regular fraction lessons (comparison group, n = 22). Students in both music programs learned to write musical notes and perform rhythmic patterns through clapping and drumming as part of their fraction lessons. They worked toward adding musical notes to produce a number (fraction), and created addition/subtraction problems with musical notes. The music programs used a 4/4 time signature with whole, half, quarter and eighth notes. In the math lessons, the students learned the analogy between musical durations and $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}$ fractions, but also practiced fractions other than $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}$. Music and math were assessed before, immediately following, and 3- and 6-months post-intervention. Pre- to post-intervention analyses indicated that only the 'MusiMath' group showed greater transfer to intervention-trained and untrained fractions than the comparison group. The 'Academic Music' group showed a trend on trained fractions. Although both music groups outperformed the comparison group 3- and 6-months post-intervention on trained fractions, only the 'MusiMath' group demonstrated greater gains in untrained fractions. Gains were more evident in trained than in untrained fractions. A video abstract of this article can be viewed at https://youtu.be/uJ_KWWDO624

KEYWORDS

elementary school, fractions, music notation, music-mathematics integrated lessons, rhythm versus melody, transfer

Correction added after first online publication: This article has been updated to include an important statement and correction for table 2.

1 | INTRODUCTION

The relation between music and mathematics has been recognized since the times of Pythagoras, Plato and Aristotle, who wrote about the overlaps and links between the two disciplines (Bamberger & Disessa, 2003). For example, the two disciplines are similarly expressed through the use of representational language and symbolic notations (Papadopoulos, 2002). The question of whether musical activities in school enhance young students' mathematical skills has attracted attention recently.

Studies that investigated the impact of musical experiences on students' mathematical skills yielded mixed results. Most studies tested instrumental music training with only an implicit connection to mathematics in the design of the intervention, showing little evidence of transfer (for a review, see Sala & Gobet, 2017). Others included explicit connections between the conceptual and procedural knowledge inherent in music and mathematics, with results indicating positive transfer effects (An & Tillman, 2015; Courey, Balogh, Siker, & Paik, 2012; for a review, see Jaschke, Eggermont, Honing, & Scherder, 2013). Because there are several overlapping relationships between mathematics and music (e.g. use of symbols, the part-whole concept, or patterns, Fauvel, Flood, & Wilson, 2006; Loy, 2006; Rauscher & Hinton, 2010), there are questions regarding the best designs of effective music instruction. Specifically, the efficacy of focusing on dissociated musical elements is controversial (e.g. rhythm only vs. rhythm within melody, Dyer, Stapleton, & Rodger, 2017; Patscheke, Degé, & Schwarzer, 2019). We replicated an intervention program that demonstrated a positive effect of explicitly connecting concepts and procedures embedded in rhythmic patterns to fraction knowledge (Courey et al., 2012), and compared it to a similar novel program, 'MusiMath', which is based on authentic musical pieces focusing on rhythm within the melody, in order to address this issue.

Research Highlights

- The current study examined the effect of two integrated music-math intervention programs (acoustic vs. holistic approach) on fraction knowledge in fourth graders.
- The 'MusiMath' holistic program utilized rhythm in melodies; the 'Academic Music' acoustic program used rhythm only; a third class served as a comparison group.
- The music programs explicitly made the analogy between whole, half, quarter and eighth notes and $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}$ fractions, and were tested 3- and 6-months post-intervention.
- An advantage in both intervention-trained and untrained fractions was found in the 'MusiMath' group versus the comparison group.

1.1 | Mathematical fractions and their parallels in music

A convergent body of research suggests that early fraction knowledge predicts later mathematics achievements. Understanding fractions is necessary for students' success in algebra. However, fractions are among the most difficult mathematical concepts to master in the elementary curriculum (Lortie-Forgues, Tian, & Siegler, 2015; OECD, 2016; Siegler & Pyke, 2013). Students are slow to master fraction concepts, even though fraction instruction begins in elementary school. A fragile understanding of fraction concepts causes students to sustain misconceptions throughout high school and into college (Schneider & Siegler, 2010; Vamvakoussi & Vosniadou, 2010).

The National Council of Teachers of Mathematics (NCTM) and common core standards (Maccini & Gagnon, 2002) related to fractions for elementary through middle school highlight conceptual and procedural knowledge. Specifically, conceptual understanding of fractions and their magnitude, utilizing visual representations and number lines, equivalence of different fraction representations, problem solving and reasoning and computations of fractions with like or unlike denominators (e.g. $\frac{1}{4} + \frac{1}{8}$) (Butler, Miller, Crehan, Babbitt, & Pierce, 2003; NCTM, 2000). The common core standards for learning fractions in grade four (NCTM, 2000) emphasize conceptual knowledge and include developing an understanding of fraction equivalence, reasoning about size, and understanding a fraction as a number on a number line. In fourth grade, computations with unlike denominators are comprised of fractions that share a common multiplier, stressing the notion of fraction equivalence.

Rhythm and the temporal value of music notes share the part-whole relation with fractions. For example, in the duple meter of 4/4 time, a whole note represents four beats, a half note equals two beats and the quarter note equals one beat. These relations reflect the conceptual knowledge of fractions required in fourth grade. Conceptual knowledge acquired explicitly by instruction and implicitly through practice is flexible and not tied to specific representations or problem types and is therefore generalizable (Rittle-Johnson, Siegler, & Alibali, 2001).

Music-math instruction programs in Western countries usually focus on the 4/4-time signature (An & Tillman, 2015; Courey et al., 2012; Ribeiro & Santos, 2017), stressing the natural equivalence between music notes and part-whole relations in powers of 2. Specifically, in fractions, the equivalence is to fractions with denominators based on division by 2 (e.g. $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}$,etc.), emphasizing transfer of knowledge from music to specific mathematical fractions.

1.2 | Transfer of skills

Transfer of learning takes place when knowledge acquired in one area is either generalized to new areas or increases general cognitive abilities. The efficiency of transfer from one academic field to another depends on the similarity of the learning process involved. Near transfer is a term used when both learning materials have a very similar context. The term far transfer is used when the skills and concepts learned in one particular context can be utilized effectively in a very different context. Students tend to demonstrate near transfer much more often than far transfer (Barnett & Ceci, 2002; Hallam, 2016; Sala & Gobet, 2017). Transfer

theories that focus on mapping suggest that transfer is based on the evaluation of structural similarities between two or more objects or concepts. Distance in transfer (e.g. near, far) denotes the *relative* degree of similarity between what is being transferred from (base), and what is being transferred to (target). Some of these theories define three, rather than two, levels of hierarchical similarity ('surface similarity', 'relations', and 'higher order relations' - see review in Forsyth, 2018). In the current study, the intervention is based on a 'surface' similarity between the 4/4 time signature and $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}$ fractions. The similarity level between the 4/4 time signature and fractions involving division of the whole by other numerals (e.g. $\frac{1}{3}, \frac{1}{5}, \frac{1}{6}$) is based on the notion of dividing the whole into parts, which is hierarchically higher than for $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}$ fractions (which is a set of specific trained divisions). Due to this difference in similarity levels, we refer to the former relation as near transfer, while the latter is considered far transfer.

1.3 | Transfer of knowledge and skills from music to mathematics

Findings related to transfer from musical experiences to mathematics achievements are inconclusive. For example, Costa-Giomi (2004) studied 117 elementary school children who received piano lessons over the course of 3 years. Children in the experimental group received weekly individual piano lessons for 3 years. Children in the control group did not participate in formal music instruction. The results indicated that piano instruction did not affect children's academic achievements in mathematics.

In contradistinction, music intervention programs that explicitly include mathematical concepts and also enable considerable amount of practice relevant to conceptual knowledge, in some of the cases implementing integrated curricula, provide evidence for transfer and a positive relation between music and improvement in mathematics achievements (An & Tillman, 2015; An, Tillman, Boren, & Wang, 2014; Courey et al., 2012; Ribeiro & Santos, 2017). For example, Courey et al. (2012) examined the effects of an 'Academic Music' intervention program on conceptual understanding of music notation, fraction symbols, fraction size, and equivalence of fractions, in third graders. The experimental music intervention included 12 sessions, delivered twice per week for 6 weeks by a music teacher and a university researcher. The control group students received the regularly scheduled math instruction. The results indicated that the 'Academic Music' students used their conceptual understanding of music to develop fraction concepts, which helped them solve fraction computation problems (Courey et al., 2012). This program was taken as evidence for near transfer from rhythm instruction to fraction knowledge (Jaschke et al., 2013).

1.4 | Two different approaches in music education

The following two perspectives regarding music instruction must be taken into account when considering transfer from music instruction to mathematical understanding: (a) the 'simple acoustic' approach; and (b) the 'holistic' approach. The 'simple acoustic' approach focuses on the elements of music (e.g. melody, rhythm, etc.) and their contribution to music understanding. Studies utilizing the 'simple acoustic' approach included short fragments of rhythm patterns, harmony or single tones to examine the process of developing an understanding of these 'building blocks' of music (Bamberger, 1991, 1999; Barrett, 2005; Steinbeis & Koelsch, 2008; Upitis, 1987). Studies utilizing the 'holistic' approach stress the need to approach music instruction through a broader vision that embraces more holistic qualities of music (Elkoshi, 2002, 2017; Kaschub, 2009; Serafine, 1988; Swanwick & Franca, 1999). Students who receive 'holistic' music instruction listen, play and create music, while also referring to musical components. Thus, while in the 'simple acoustic' approach musical materials specifically focus on musical elements (e.g. rhythm), in the holistic contextual approach, authentic musical pieces are used to engage students (Wiggins & Espeland, 2018).

1.5 | Advantage of melody over rhythm in transfer from music to other skills

Some researchers argue that pitch and rhythm represent two disassociated dimensions of music, based on their processing in at least partially nonoverlapping brain areas (Carroll-Phelan & Hampson, 1996; Peretz & Kolinsky, 1993). Hallam (2015) reviewed studies that tested the impact of rhythm as opposed to combined rhythm and pitch (melody) training on reading comprehension. The study findings suggested that musical instruction that develops understanding of melody skills also supports the development of reading fluency and enhances comprehension. Furthermore, melody perception was found to predict early reading performance (Anvari, Trainor, Woodside, & Levy, 2002), and implementing a music program that includes melody was found to significantly improve phonological awareness (Patscheke & Degé, 2019).

Dyer et al. (2017) tested bimanual motor coordination in order to examine the effect of rhythm and melody feedback on developing complex motor skills. Their findings suggest that melodic sonification of movement provides an advantage over augmented feedback, which only provides timing information. The benefit of melody was conceptualized in terms of extra, useful information in an additional auditory dimension and positional information of the order in which subsequent movements must be performed.

1.6 | The current study

In the current study, we explored the effect of two intervention programs, the 'Academic Music' (Courey et al., 2012) and 'MusiMath' programs that utilize music instruction to enhance fraction knowledge. We designed our music instruction to include elements from the 'simple acoustic' or 'holistic' approach to teaching music, and follow-ups at 3- and 6-months post-intervention. The 'simple acoustic' approach, represented by the 'Academic Music' program, uses the instruction of rhythmic patterns. This program was initially tested in the US on third graders (Courey et al., 2012). The current study was conducted outside the US and on fourth graders (in accordance with national guidelines for fraction learning). Because the main findings of Courey et al. (2012) study may be culture and age-dependent (Anderson & Maxwell, 2016; Simons, 2014), the 'Academic Music' program was replicated as a basis for comparison with a holistic

approach program. Employing elements from the holistic approach, we created the 'MusiMath' program to examine the effect of rhythmic instruction to melodies on fraction knowledge.

Instruction in both programs shows the relations of musical rhythms to different sizes of fractions via several learning modalities (i.e. visual, auditory, and kinesthetic). Fourth graders learned to write musical notes and perform basic rhythmic patterns through clapping and drumming. They worked toward adding musical notes together to produce a real number (fraction), and created addition/subtraction problems with musical notes.

We examined the near transfer of music skills and concepts to fractions with denominators based on division by 2 (i.e. $\frac{1}{2},\frac{1}{4},\frac{1}{8}$). We also studied 'other' fractions (e.g. $\frac{1}{3},\frac{1}{5},\frac{1}{6}$), not practiced in the rhythmical activities, in order to examine far transfer. The inclusion of musical pieces that reflect more than rhythm (e.g. reflecting melody, which conveys additional natural divisions) may further enable far transfer to fractions with denominators based on division other than 2, while analyzing such pieces as part of the intervention.

The ability to track temporal structures relies on the dynamic interaction between prediction, conflict monitoring, and error correction. A recent study showed that drumming to a rhythm is associated with inhibitory control (Slater, Azem, Nicol, Swedenborg, & Kraus, 2017). Inhibitory control and cognitive flexibility, two important executive function (EF) components, are strongly associated with early academic achievements (McClelland et al., 2007, 2014). Research suggests concurrent associations between EF and mathematical skills, and to a lesser extent as predicting future achievements or mediating the effect of curricular programs (Clements, Sarama, & Germeroth, 2016; McKinnon & Blair, 2019). These skills were assessed in the current study.

1.7 | Study hypotheses

1. The positive effect of a previously studied near transfer intervention program that builds on the relation between the temporal value of a music note and equivalent $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ fractions (Courey et al., 2012) is expected to be replicated.
2. Similar positive effects on the near transfer of music notes to $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ (trained) fractions are expected to be found in the comparison between the holistic 'MusiMath' program and the acoustic 'Academic Music' program (Courey et al., 2012). We expected far transfer effects from music instruction to 'other' (untrained) fractions (e.g.$\frac{1}{3},\frac{1}{5},\frac{1}{6}$) in the 'MusiMath' group, but not in the 'Academic Music' group.
3. We expected concurrent associations between EF measures and mathematics and music scores at pretesting. Furthermore, the explicit nature of music instruction is expected to facilitate an association between EF measures and gains in musical note knowledge. While EF is often assessed in studies of instrument playing programs (Bialystok & DePape, 2009; George & Coch, 2011), we did not find previous studies on music-math intervention programs that do not include instrument instruction that assesses measures of EF. Nevertheless, we expected associations between EF at pretesting and learning gains in math.

2 | METHOD

2.1 | Participants

The participants included 77 9-year-old fourth graders without previous musical training, studying in three classrooms of the same elementary school in Israel operated and supervised by the Ministry of Education (MOE), from a middle socioeconomic background (Central Bureau of Statistics, 5/10). Approval was obtained from the Ministry of Education (10.32/399/2016), and the parents of the children signed the Ministry of Education's consent forms. The classrooms were randomly assigned to three conditions: A 'MusiMath' class (n = 30), an 'Academic Music' class (n = 25) and a third class (n = 22), that served as a control group.

2.2 | Experimental procedures

All three study groups received 12 standardized 40-min lessons delivered twice a week during the regularly scheduled mathematics instruction (the students learned six math lessons every week; two fraction lessons and four other math lessons). All classes followed the MOE math program emphasizing the meaning of fractions, fraction names, understanding equal parts of a whole, meaning of the equal sign and equivalence and adding and subtracting fractions with like and unlike denominators, restricted to cases of fractions that share a common multiplier.

The two music intervention programs, 'MusiMath' and 'Academic Music', are based on the Kodaly system of music education, which emphasizes learning through several modalities (i.e. visual, auditory and kinesthetic; Wheeler & Raebeck, 1985). Students learn to read and write specific notations to a rhythm and simultaneously gesture and chant. The music programs focus on measures of the 4/4 time signature (including a whole note, half note, quarter note and eighth note) corresponding to the $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ fractions, while the math teacher taught fractions with other denominators.

The music teacher demonstrated how to recite, clap and write patterns of music, each comprising four measures of note patterns. First, the students learned the four quarter notes as the basic beat of the bar (four claps). Then they learned to hold the second, third and fourth beats, so they got a whole note in fourth time. Afterward, the students learned to recite, clap and write two half notes in a bar and eight eighth notes in a measure in the same way. Through rhythm, they practiced the varied amount of time and length and naturally related it to a fraction of the whole.

As instruction progressed, the music teacher continued to demonstrate how to drum the rhythmic pattern by using a tambourine, drumsticks, and triangles while chanting the Kodaly syllabic name and the fractional name of each note. The students practiced arranging varied repeated patterns of notes in each measure of four fourth time. They compared the music notes' values and fraction symbols to the equivalent portions of each representation (see Figure 1). The music teacher was able to guide the students toward connecting music instruction to more formal mathematics

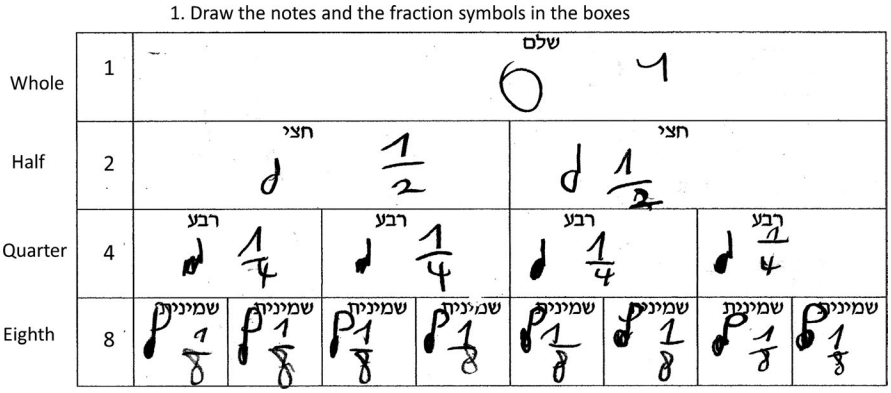


FIGURE 1 Sample of students moving between fraction bars, musical notes, and fractions

language, representations, and symbols (see Figure 2). Fraction circles, fraction bars, and the number line were introduced in succession so that the students had an opportunity to partition various representations of wholes into equal parts. Students learned to 'trade in' notes or 'break up' the larger notes or fraction values into the smallest quantity that was in the computation problem (see Figure 3). Addition and subtraction of fractions with unlike denominators were taught in this way (see Figure 4). While the students learned how to add and subtract notes, the math teacher showed how they can add and subtract the corresponding intervention-trained fractions as well as untrained fractions with other denominators. We monitored the students' understanding and provided feedback as they practiced the music and math tasks. Each day, classroom worksheets were collected and scored for accuracy.

The programs differed, however, in two respects: (a) the 'MusiMath' program included holistic music instruction which involved listening to music and writing rhythmical patterns to musical pieces, while the 'Academic Music' program focused only on writing rhythmic patterns; (b) based on An and Tillman's (2015) mixed-lesson approach, the 'MusiMath' program included 12 mixed music (20 min) and math (20 min) sessions. The 'Academic Music' program included six music lessons (40 min) followed by six mixed music (20 min) and math (20 min) lessons.

Students in the two music programs completed similar worksheets (adjusted to the musical pieces or rhythm, Appendix A, Tables A1 and A2). The workplan in the two programs covered the same topics but used a different time schedule. The children in all three classes worked on worksheets with the same amount of exercises (music and math in the intervention classes, math in the comparison group), and received the same homework (math only).

2.2.1 | 'MusiMath' intervention

During the 'MusiMath' intervention, the students listened to several musical pieces: a part of Handel's Concerto Grosso Op. 6 No.7; a part of Vangelis' Heaven and Hell; and folk songs (Table A1). These musical pieces demonstrated the division of time in music, and the students could hear the proportional values of the notes being played

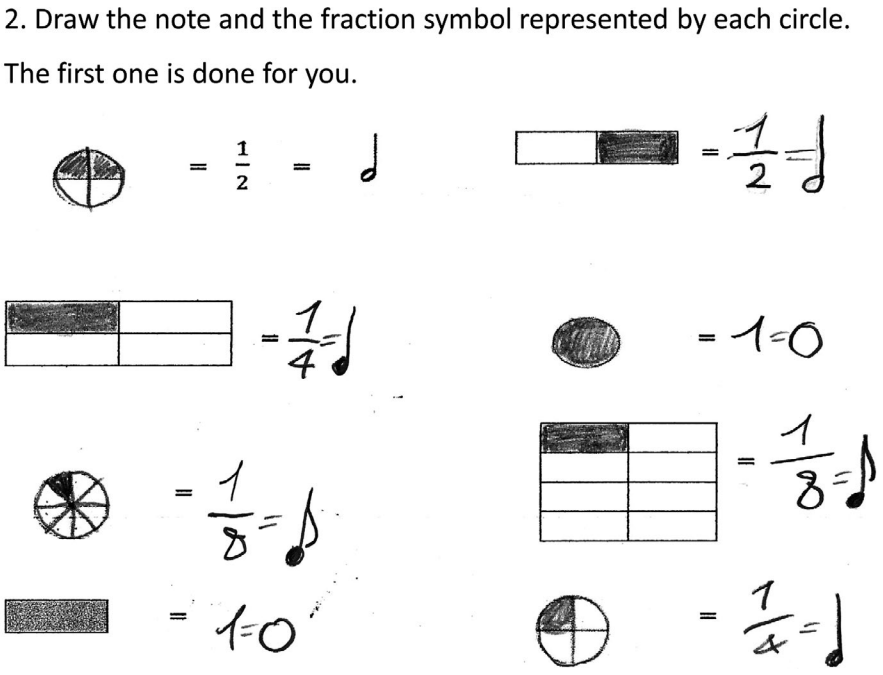
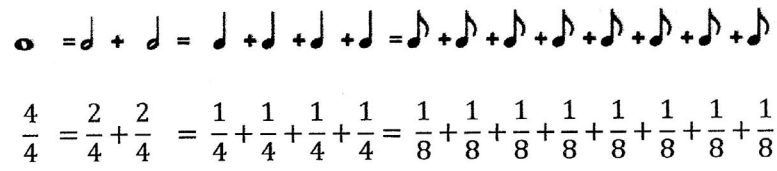
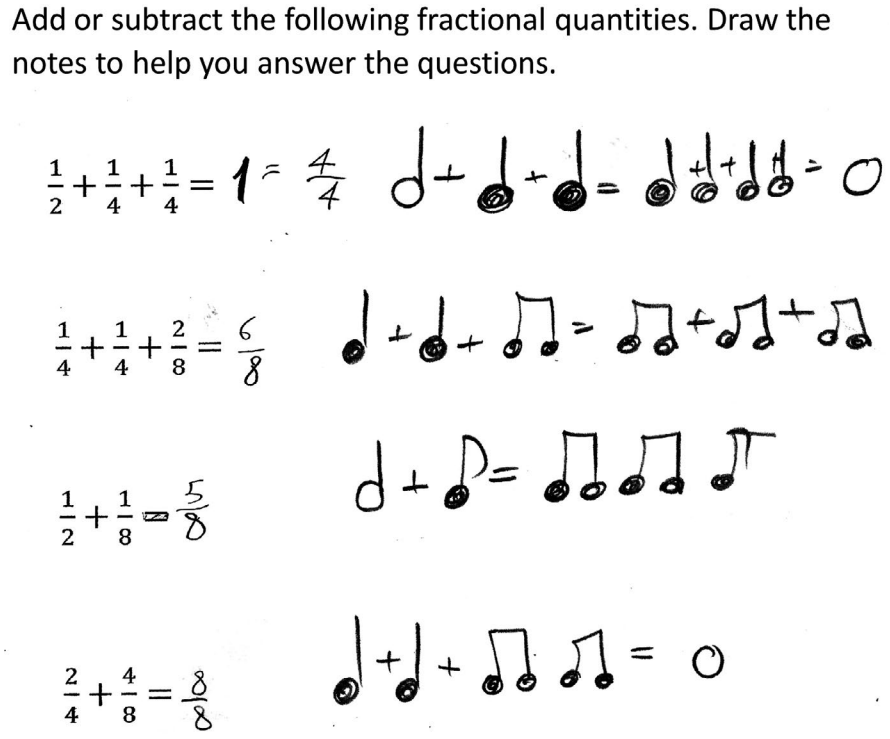


FIGURE 2 Sample of students moving between circles, fraction tiles, notes, and fraction symbols



$$\frac{4}{4} = \frac{2}{4} + \frac{2}{4} = \frac{1}{4} + \frac{1}{4} + \frac{1}{4} + \frac{1}{4} = \frac{1}{8} + \frac{1}{8} + \frac{1}{8} + \frac{1}{8} + \frac{1}{8} + \frac{1}{8} + \frac{1}{8} + \frac{1}{8}$$

FIGURE 3 Sample of students adding fractions with unlike denominators by notes



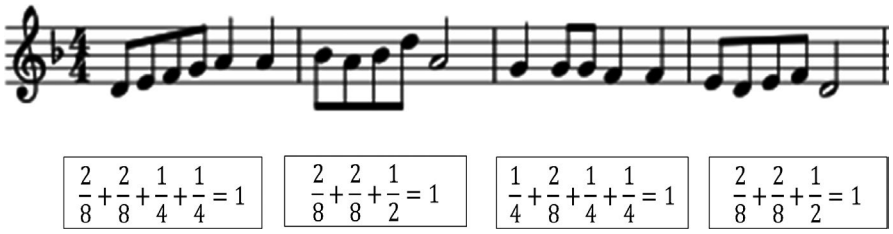


FIGURE 4 Sample of students moving between notes and fraction symbols

while learning to write the rhythmic pattern. The music and the math teachers used the same fractional terminology in order to understand the division of the time as well as the number.

Each of the 12 lessons followed the same instructional sequence. First, the students clapped, chanted, and drummed the music patterns following the Kodaly approach (see Wheeler & Raebeck, 1985) in order to review the last lesson (5–7 min). Next, a new musical piece was introduced (13–15 min) and the students practiced writing notes and filling in a whole measure. Then, in the math teacher's 20 min lesson, the students were taught to connect the fraction symbol with the musical note and with other representations of fraction quantities using worksheets, and learned to parallel musical notations and fraction symbols. They were also taught to add and subtract fraction quantities with or without unlike denominators. Double-sided worksheets that included music page problems and fraction page problems were used, according to the content taught in each lesson.

2.2.2 | 'Academic Music' intervention

The 'Academic Music' intervention replicates Courey et al. (2012) study (described in detail in Courey et al., 2012). The first six lessons (40 min each) focused on music notation and the temporal value of musical notes in 4/4-time signature. The last six lessons focused on connecting the proportional values of the musical notes to other signs or fractions (Table A2). Each lesson followed the same instructional sequence. First, the students 'played' the music measures by drumming with drumsticks on a table (2–3 min). Next, the music teacher reviewed the previous lesson and introduced the day's objectives (10 min) and the students practiced writing notes and filling in a whole measure. Then, the students learned new material (8 min). In the remaining 20 min, the students completed double-sided worksheets, either with the music or the math teacher, depending on the content taught in each lesson.

2.2.3 | The comparison group

Students in the comparison group were taught fractions by the regular classroom teacher for 12 40-min lessons. The students worked in their textbooks and notebooks, which are standardized by the MOE. In the first two lessons, the math teacher began with teaching the meaning of fractions. This was followed by lessons 3–4, in which the students learned to utilize fraction bars and circles to understand parts of the whole while the teacher presented fractions with a numerator bigger than 1. In the next four lessons, the students focused on the concept of fraction size and equivalence. Finally, in the last four lessons, the students learned to add and subtract fractions with like and unlike denominators. Each lesson began with a short review of the last lesson and continued with a new subject. The teacher used fraction tiles, circles and number lines to demonstrate the fraction subject. The lessons included 20 min of teaching followed by 20 min of individual work in the notebooks and textbooks.

2.2.4 | The math curriculum after the intervention programs

At the end of the intervention period, the students continued to learn 12 traditional fractions lessons from the standard curriculum with their math teacher until the end of the school year. They briefly rehearsed the previous topics that were learned in the experiment (2–3 lessons) and continued learning about mixed numbers, the fraction as a part of a quantity, word problems and adding and subtracting fractions of mixed numbers. These topics were not examined in the 3- and 6-months posttests.

2.3 | Mathematics ability indices

2.3.1 | General mathematics skills

A Hebrew version of the math subtest of the WISC R-95 was administered (Ryan, Utley, & Worthen, 1988; Wechsler, 1998). This is a progressively difficult test with 24 questions. Each correct answer is credited one point, and the test is stopped after three consecutive failures.

2.3.2 | Fraction tests

The fractions tests aimed at testing the content taught by the schoolteachers, according to the MOE program. Test items were adapted from the standardized examination for fourth grade (Mevarech & Kramarski, 1997). The test included items using a number line, set representations equivalence of fractions, and addition and subtraction of fraction with like and unlike denominators.

The pre- and post-intervention fractions tests were identical: 40% of the questions related to the spatial representation of fractions (conceptual knowledge) and 60% related to formal fraction operations. We replicated the structure of Courey et al. (2012) test, where intervention-untrained fractions appeared only in questions on the spatial representation of fractions, and comprised 15% of the overall test scores, whereas intervention-trained fraction questions also included questions of formal operations. The tests given 3- and 6-months post-testing were identical in structure, but untrained fraction questions were included in conceptual knowledge and in calculation questions in order to allow a more comprehensive test of transfer. Cronbach's alpha ranged between 0.73 and 0.79. The maximum test score was 100, with eight questions providing an opportunity for more than one answer (see Figure 5).

2.3.3 | Music worksheets

Twelve music worksheets were administered to the students in the experimental groups, one in every session. Conceptual knowledge was assessed by asking students to write musical notes, write rhythmical patterns in 4/4-time signature, and convert musical sounds to musical notations. Procedures of fraction computation included addition and subtraction of musical notations and interpretation of the result in terms of music duration (Courey et al., 2012).

2.3.4 | Fraction worksheets

Twelve fraction worksheets were administered, one in every session in the 'MusiMath' group, and two in each of the last six sessions in the 'Academic Music' group, while students in the comparison group worked in their textbooks and notebooks. Conceptual knowledge was assessed by testing the relation between the fraction and spatial representations of the whole unit. Procedures of fraction computation included addition and subtraction of fractions with similar and different denominators (Courey et al., 2012).

2.4 | Musical ability

2.4.1 | Music test

The music test was adopted from Courey et al. (2012) and included items that ask the students to identify musical notes, match the fraction that parallels the value of the note, and add and subtract notes and fractions to maintain 4/4 time in each measure (see Figure 6). The maximum score for this measure was 100.

2.5 | Executive functions

2.5.1 | Stroop test

This is a neuropsychological test for assessing inhibitory control. The participant looks at (a) words naming the colors black, blue, yellow, green or red, printed in black, (b) 'X' printed in these colors, and (c) words naming the colors, which appear in different colors that do not match the color words. The participant is asked to indicate the color in which the word is written as fast and as accurately as possible, and not read the word per se. Response

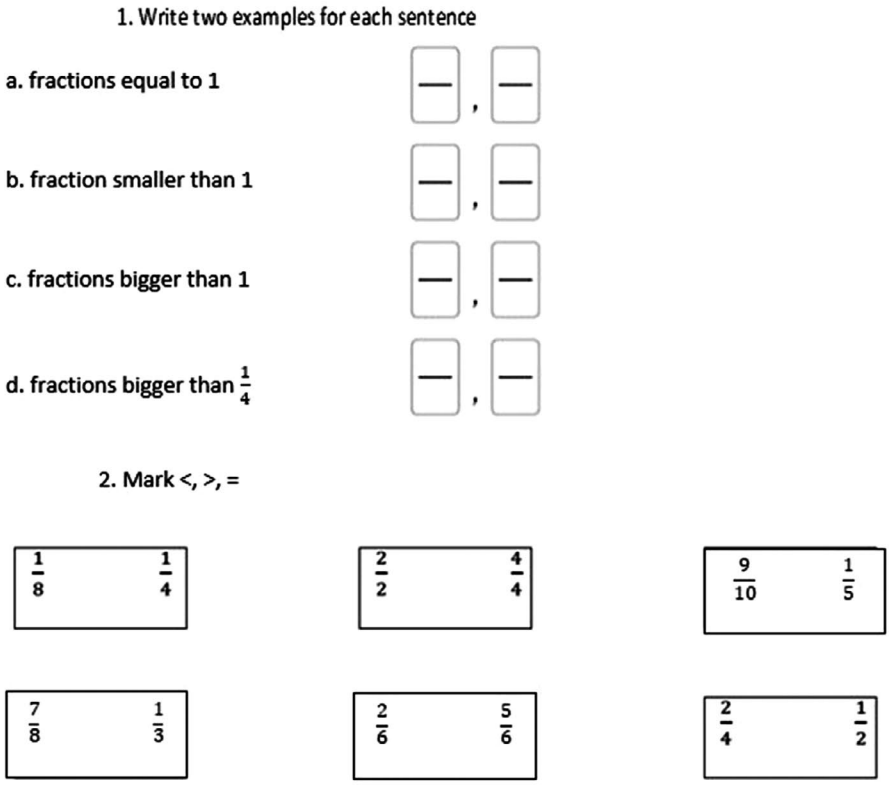


FIGURE 5 A part of the fraction test

time and accuracy were assessed using an iPad (Zysset, Müller, Lohmann, & Cramon, 2001).

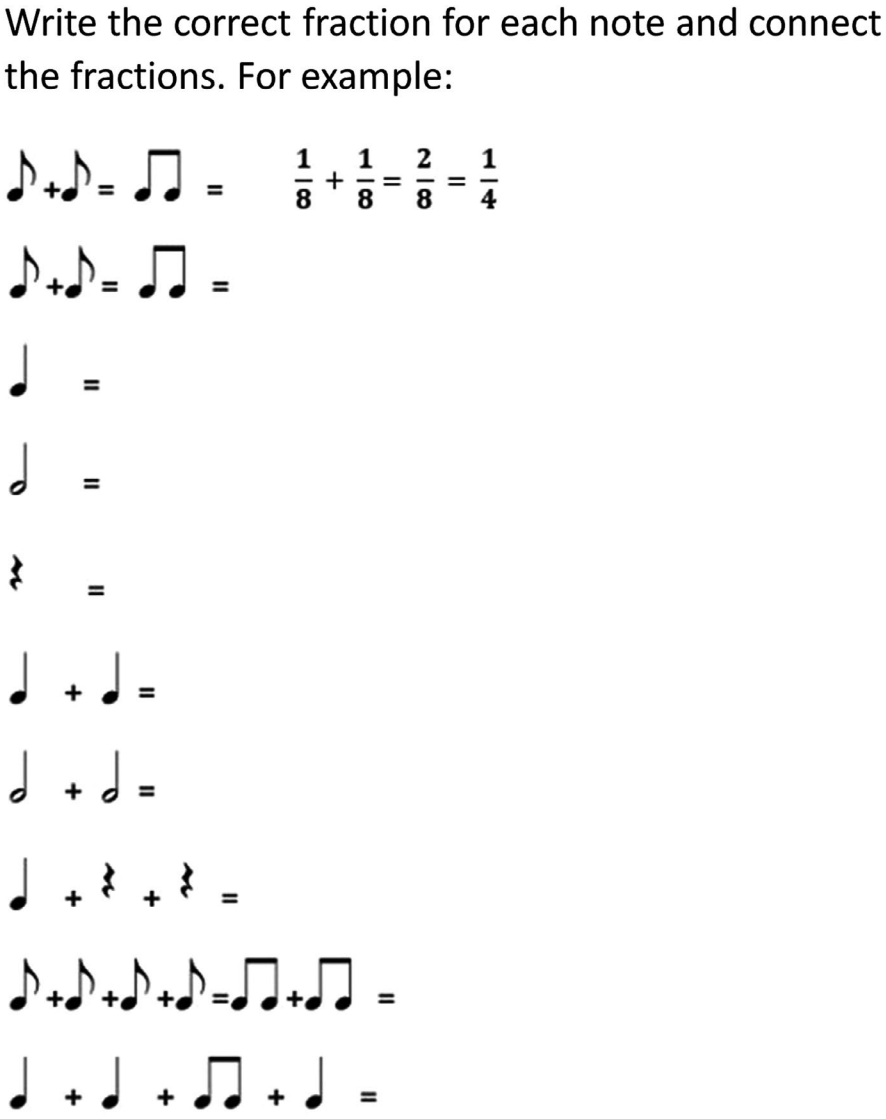
2.5.2 | The Trail Making Test (TMT)

This is a neuropsychological test that assesses speed of processing (Part A) and working memory and cognitive flexibility (Part B) (Sánchez-Cubillo et al., 2009). It is comprised of two parts in which the participant is asked to connect numbers in ascending order by means of pencil lines as fast and accurately as possible. In the first part, the participant needs to connect numbers from 1 to 25 and in the second part, the participant needs to alternately connect a number and a letter (1–13, A-M) (Hebrew version, Vakil, Blichshtain, & Shiman, 2010).

2.6 | Experimental design and data analysis

A 3 × 2 repeated-measures ANOVA of Group ('MusiMath'/'Academic Music'/comparison) × Time (pre-intervention/post-intervention) was performed to analyze intervention gains in fraction test scores, with time as the repeated-measures variable. Interaction contract analysis (Keppel, 1991) was used to study the Group × Time interaction. This method uses the estimate of the variability from the simultaneous comparison of all the conditions in the pairwise comparisons. A 2 × 2 repeated-measures ANOVA of intervention Group ('MusiMath'/ 'Academic Music') × Time (pre-/post-intervention) was undertaken in order to compare between the 'MusiMath' and 'Academic Music' groups' test scores in music. Three and 6-months post-intervention, one-way ANOVAs

FIGURE 6 A part of the music test



were used to compare fraction test scores between the three groups.

The intervention analyses compared three outcomes: overall test scores (for comparison with Courey et al., 2012), trained and untrained fraction test scores. Alpha/3 was therefore used in the repeated-measures ANOVAs as a significance criterion, with an alpha level of 0.05. The 3- and 6-months post-intervention ANOVAs referred only to trained and untrained fractions, and alpha/2 was used to indicate significance level. The corrected alpha level for the ANOVA tests is indicated in the text and tables. For simplicity, all post-hoc pairwise comparisons that followed the ANOVA tests used alpha/3 as a significance criterion with the notation 'Bonferroni' (i.e. if the analysis indicated $p = .01$, we here report: Bonferroni, $p = .03$).

In order to study the association between EF and gains in notation writing and math scores, correlation analyses were performed using an averaged EF measure. Regression analyses followed the correlations.

3 | RESULTS

Table 1 shows descriptive statistics and students' mean scores and standard deviations for pretest performance. A one-way ANOVA comparing the pretest mean scores across the three groups revealed no significant differences. There were no gender differences between the groups, χ^2 (2) = 0.16, $p = .88$.

3.1 | Math knowledge

Math knowledge at pre- and post-intervention testing was analyzed using the math tests presented by Courey et al. (2012), in order to enable replication of Courey et al. (2012) study. In these tests, trained fraction testing (i.e. $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}$) includes knowledge of spatial representation as well as questions of formal operations, while untrained fractions (e.g. $\frac{1}{3}, \frac{1}{5}, \frac{1}{6}$) appeared only in questions on the spatial representation of fractions. To allow for a more comprehensive test of transfer at 3- and 6-months post-testing,

TABLE 1 Descriptive statistics: Sample and pretesting scores

	Comparison group (n = 22)		MusiMath group (n = 30)		Academic music group (n = 25)		η^2	F	p
Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*			
Gender (% male)	0.50		0.46		0.52				
Age	115.2	4.01	114.6	5.21	113.9	3.51	0.01	0.52	.60
Pre-Math	23.05	17.74	17.53	8.68	22.32	19.32	0.03	1.03	.36
Pre – $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ fractions	22.03	17.01	17.59	8.97	21.09	19.76	0.02	0.61	.54
Pre – other fractions	28.45	27.37	16.63	15.50	29.02	21.24	0.07	2.97	.06
Pre-Music			6.53	3.85	7.68	4.75	0.02	0.97	.33
Stroop time	43.27	9.48	42.63	8.33	43.92	8.39	0.01	0.15	.86
Stroop error	0.90	1.65	1.97	2.47	1.68	1.31	0.05	1.96	.15
TMT time	99	24.30	106.03	29.02	97.92	26.74	0.02	0.73	.48
TMT error	0.90	1.26	1.20	1.42	1.36	1.18	0.02	0.71	.49
WISC Math	14.91	1.57	14.90	1.90	15.04	1.74	0.00	0.65	.95
Attendance	11.27	1.19	11.07	1.01	10.96	1.91	0.01	0.25	.77

Note: Pre = pretest. The Pre-Math test included the Pre – $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ (trained) fractions (85%) and the Pre – other (untrained) fractions (15%). Correction of alpha level indicated $p < .017$ as significance threshold for fraction test scores. Stroop = color-word task. TMT = Trial Making Test Part B. WISC = Wechsler Intelligence Scale for Children. Attendance = number of lessons attended (of 12).

TABLE 2 Music and math score: Pre- and post-intervention scores

	Pre		Post	
Groups	*M*	*SD*	*M*	*SD*
Music scores				
'MusiMath'	6.53	3.85	88.73	11.77
'Academic Music'	7.68	4.75	86.76	12.50
Math scores				
'MusiMath'	17.53	8.68	82.10	16.20
'Academic Music'	23.32	8.68	82.72	15.15
Comparison	23.05	17.74	73.05	12.73

the assessment of untrained fraction skills was broadened to include formal calculation questions paralleling questions on the trained fractions. Due to this difference in post-intervention testing, separate analyses were conducted for the pre- to post-intervention testing and for the 3- to 6-months post-intervention period.

3.1.1 | Pre- to post-intervention testing—replication of Courey et al. (2012)

The math scores of the three groups are presented in Table 2. It should be noted that there were no group differences at pretesting (Table 1). The analysis of the intervention gains (see Table 3) indicated significant gains in math scores, revealing that all groups improved their performance. However, the magnitude of improvement differed between the groups, with the largest gains attained by the 'MusiMath' group and the smallest gains by the comparison group. Interaction contrast analysis indicated greater improvement in the 'MusiMath' group than in the comparison group ($F(1,50) = 10.00$, Bonferroni, $p < .01$, $\eta^2 = 0.17$). The gains obtained by the 'Academic Music' group were higher than those obtained by the comparison group. However, the analysis only showed a trend, that did not withstand the Bonferroni correction ($F(1,45) = 4.70$, Bonferroni, $p = .12$). No difference emerged between the two intervention groups.

3.1.2 | Pre- to post-intervention testing—trained fractions

No group differences emerged at pretesting (Table 1, Figure 7a). The analysis of pre- to post-intervention of the trained fractions scores, which comprised 85% of the overall test scores, replicated the results of the overall test scores, including a significant Group × Time point interaction (Table 3). Interaction contrast analysis indicated greater improvement in the 'MusiMath' than in the comparison group ($F(1,50) = 8.18$, Bonferroni, $p < .05$, $\eta^2 = 0.14$). The 'Academic Music' group gained more than the comparison group. However, the analysis only showed a trend, that did not withstand the Bonferroni correction ($F(1,45) = 4.46$, Bonferroni, $p = .12$). No difference emerged between the two intervention groups.

3.1.3 | Pre- to post-intervention testing—untrained fractions

No significant group differences emerged at pretesting (Table 1, Figure 7c). The analysis of pre- to post-intervention replicated the results of the overall test scores, including the significant Group × Time

TABLE 3 Analyses of pre- to post-intervention gains in Mathematics and in music, and group-specific intervention gains

	Pre- to post-intervention				Group-specific gains			
	df	*F*	η^2	*p*		*df*	*t*	*d*
Overall test scores								
Group	2, 74	0.74	0.02	.48	MusiMath	29	22.64***	4.20
Time point	1, 74	957.40	0.93	.001	Academic Music	24	16.52***	3.37
Group X Time point	2, 74	5.01	0.12	.008	Comparison	21	15.47***	3.37
$\frac{1}{2},\frac{1}{4},\frac{1}{8}$ *fractions*								
Group	2, 74	0.69	0.02	.50	MusiMath	29	19.52***	3.62
Time point	1, 74	815.44	0.92	.001	Academic Music	24	15.21***	3.10
Group X Time point	2, 74	4.29	0.10	.017	Comparison	21	15.54***	3.39
Untrained fractions								
Group	2, 74	2.05	0.05	.13	MusiMath	29	25.60***	4.75
Time point	1, 74	692.15	0.90	.001	Academic Music	24	15.84***	3.23
Group X Time point	2, 74	4.51	0.11	.014	Comparison	21	9.25***	2.02
Music scores								
Group	1, 53	0.05	0.00	.83	MusiMath	29	41.24***	7.66
Time point	1, 53	2,848.92	0.98	.000	Academic Music	24	34.55***	7.05
Group X Time point	1, 53	1.07	0.02	.31				

Note: Correction of alpha level indicated $p < .017$ as significance threshold for fraction test scores.
***$p < .001$.

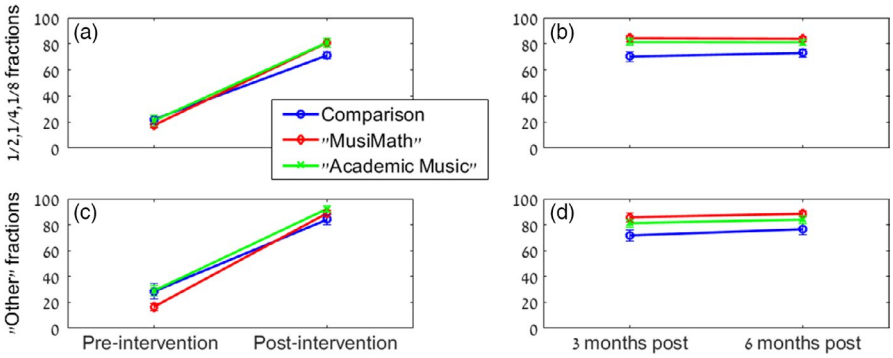


FIGURE 7 Fraction test scores (M and SE). A and B: $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ (trained) fractions. C and D: Untrained fractions. Fraction scores were scaled to a maximum score of 100

point interaction (Table 3). Interaction contrast analysis indicated greater improvement in the 'MusiMath' than in the comparison group ($F(1,50) = 8.83$, Bonferroni, $p < .05$, $\eta^2 = 0.15$). No difference emerged between the 'Academic Music' group and the comparison group or the 'MusiMath' group.

As can be seen in Table 1, the 'MusiMath' group scored marginally lower than the other two groups on the untrained fractions pretest (Table 1: ANOVA, $F(1, 74) = 2.97$, $p = .06$, where $p < .017$ indicates significant ANOVA results, pairwise comparisons, Bonferroni, *ps* > .10). Although insignificant, it may have enabled the higher intervention gains of this group. Due to this difference, the study analyses were repeated for two matched subsamples of 19 participants from each group that had the same range of untrained fractions test scores. These additional analyses (Appendix B) replicate the pattern of significance reported for the full sample, but to a trend toward significance in the analysis of intervention gains in untrained fractions.

3.1.4 | Three- and 6-Months post-intervention scoring – Trained fractions

Three- and 6-months post-intervention, the two intervention groups outperformed the comparison group (3 months post: $F(2,74) = 6.19$, $p < .01$, $\eta^2 = 0.14$, Bonferroni $p < .01, .05$; 6 months post: $F(2,74) = 4.98$, $p < .01$, $\eta^2 = 0.12$, Bonferroni $p < .01, .05$; $p < .025$ indicates significant one-way ANOVA results; Bonferroni reported for 'MusiMath' and 'Academic Music' versus comparison group, respectively). No significant difference emerged between the two intervention groups on the trained fractions test scores.

3.1.5 | Three- and 6-Months Post-Intervention Scoring - Untrained fractions

Three- and 6-months post-intervention, the 'MusiMath' group outperformed the comparison group ($F(2,74) = 3.88, 4.15$, *ps* < 0.025,

η^2 = 0.10, 0.09; Bonferroni, *ps* < 0.05, 3- and 6-months post-intervention, respectively; $p < .025$ indicates significant ANOVA results), with no significant difference between the 'Academic Music' group and the 'MusiMath' or comparison groups on untrained fractions test scores.

Due to the difference between the three groups in untrained fractions pretest scores (Table 1), the 3- and 6-months post-intervention analyses were repeated while controlling for these pretest scores. The findings remained unchanged ($F(2,73) = 5.57, 6.32$, *ps* < 0.01, η^2 = 0.13, 0.15; Bonferroni, *ps* < 0.01, 3- and 6-months post-intervention, respectively).

3.2 | The intervention program: Music knowledge

The comparison between the 'MusiMath' and 'Academic Music' groups' test scores in music (Table 2) showed an overall improvement in test scores, indicating that the students' post-intervention scores were higher than their pre-intervention scores (Table 3). No group differences or Group × Time interaction emerged.

3.2.1 | Musical notation in relation to fraction knowledge

In the described intervention programs, notation writing was practiced for achieving transfer between music and mathematics. It is therefore important to study the association between gains in notation writing and in math scores. Correlation analyses indicated that gains from pre- to post-intervention in music test scores and gains in fraction test scores were correlated in both intervention groups. The correlation was marginally higher in the 'MusiMath' group than in the 'Academic Music' group ('MusiMath' $r(30) = .74$, $p < .001$; 'Academic Music' $r(25) = .42$, $p < .05$; $z = 1.75$, $p = .08$).

Students of both intervention programs filled worksheets in music and mathematics. A comparison of the worksheets between the two intervention groups showed no differences in scores (*t's* < 1.38, *p's* > 0.17). We grouped the worksheets in music and math according to whether children practiced conceptual knowledge or procedural skills. Correlation analysis indicated an association between music and math worksheet scores ('MusiMath' program: $r(30) = .46, .47$, $p < .05, .01$; 'Academic Music': $r(25) = .49$, $r(25) = .42, .46$ $p < .05$, for fraction concept and computation, respectively). These data stress the notion of parallel progress in music and math.

3.3 | EF as an explanatory variable for intervention gains

Higher EF scores (Z transformed and averaged across the Stroop and TMT speed and accuracy scores) were correlated with higher math and music pretest scores ($r = .46, .45, .38$, *ps* < 0.001, for the math overall, for trained and for untrained fractions, respectively; and $r = .27$, $p < .05$, for the pre-music test). Table 4 presents the associations between averaged EF and gains in math and music test scores. Due to the difference in EF components, the specific correlations with the Stroop (inhibitory control) and the TMT (working memory and cognitive flexibility) tests are reported as well.

A regression analysis with gains in the three measures of the fraction test scores as dependent variables (overall, trained and untrained fractions) and with Group and EF tests as predictors was performed in order to test whether there was an overall effect of EF. As a pretest, we verified that there were no interactions between the Group variable and EF measures. The analysis indicated that apart from a main effect of Group, EF scores did not add significantly to the explained variance (even when entered separately). Post-hoc analysis of the group main effect replicated the findings reported for the improvements from pre- to post-intervention in the above-reported fractions test scores. In contradistinction, the gain in music test scores was explained by the Stroop, time and error variables ($B = -3.78$, $SE = 1.37$, $t = 2.76$, $p < .01$; B = −5.18, $SE = 1.24$, $t = 4.18$, $p < .001$), (Total $R^2 = .38$). These data suggest that children who had better inhibitory control improved more in note conceptual knowledge and calculations.

Table 5 shows the point in time where the association between gains in music test scores and fraction (trained/untrained) test scores emerged (at pre/post/3-month post/6-months post-intervention). No correlation emerged between gains in music test scores

TABLE 4 Descriptive statistics – Pearson correlations between intervention gain scores and EF

	Comparison group (*n* = 22)			'MusiMath' group (*n* = 30)				'Academic Music' group (*n* = 25)			
Intervention gain scores	Test	$\frac{1}{2},\frac{1}{4},\frac{1}{8}$	Other	Test	$\frac{1}{2},\frac{1}{4},\frac{1}{8}$	Other	Music	Test	$\frac{1}{2},\frac{1}{4},\frac{1}{8}$	Other	Music
Averaged EF	0.25	0.22	0.22	−0.26	−0.28	0.05	−0.44*	−0.13	−0.19	−0.19	−0.65**
TMT time	0.22	0.24	0.09	−0.05	−0.01	−0.09	−0.11	0.01	0.01	0.02	−0.36
TMT error	0.09	0.15	−0.12	−0.12	−0.15	0.14	−0.14	−0.06	−0.06	−0.03	−0.32
Stroop time	0.08	0.02	0.23	−0.29	−0.30	−0.08	−0.28	−0.23	−0.21	−0.26	−0.40*
Stroop error	0.32	0.27	0.30	−0.31	−0.12	0.11	−0.34	−0.04	−0.05	0.04	−0.63**

Note: Test = Math test. The test included the $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ fractions (85%) and the other fractions (15%). $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ = trained fractions. Other = untrained fractions. Averaged EF = the average of the four EF tests; this is the main variable under study. Stroop = color-word task. TMT = Trial Making Test Part B.
**$p < .01$.
*$p < .05$.

TABLE 5 Pearson correlations between pre- to post-intervention gains in music and fraction test scores

	$\frac{1}{2},\frac{1}{4},\frac{1}{8}$ fractions				Untrained fractions			
	Pre	Post	3m Post	6m Post	Pre	Post	3m Post	6m Post
Zero order correlation								
'MusiMath'	−0.04	0.74***	0.64***	0.65***	0.20	0.37*	0.73***	,69***
'Academic music'	0.18	0.76***	0.72***	0.69***	0.17	0.31	0.35	0.54**
Partial Correlation – Controlling for Stroop scores								
'MusiMath'	−0.17	0.70***	0.52**	0.54*	0.07	0.29	0.78***	0.63***
'Academic music'	−0.12	0.60***	0.50**	0.40*	0.14	0.13	0.22	0.37

Note: Pre/Post = Pre/Post-intervention, 3m Post = 3-month post-intervention. 6m Post = 6 months post-intervention.
***$p < .001$.
**$p < .01$.
*$p < .05$.

and the pre-intervention test in both intervention programs. There was, however, a significant correlation between the gain in music test scores and all post-intervention–trained fraction scores in both programs. This pattern of correlations suggests that the association emerged due to the intervention. Note that a significant correlation between the gain in music test scores and *all* post-intervention–untrained fractions scores emerged only for the 'MusiMath' group, stressing this program's advantage for untrained fractions. The lower association in the post-intervention test for untrained fractions may have emerged because untrained fractions appeared only in the spatial part of the test.

Due to the association between Stroop scores and the gain in music test scores (Table 4), the correlation analyses were repeated while controlling for Stroop scores (speed and accuracy, no significant correlation emerged between these variables). The results indicated that the association between the gains in music scores and the trained fractions test scores remained significant. However, for untrained fractions, only the correlation with 3- and 6-months post-intervention scores in the 'MusiMath' group remained significant.

4 | DISCUSSION

The present study compared two music instruction programs, 'Academic Music' and 'MusiMath', that connect parallel aspects inherent in rhythms and in fractions, in order to enhance knowledge of fractions in fourth graders. While the 'Academic Music' program was based on rhythm instruction, the 'MusiMath' program used authentic musical pieces focusing on rhythms within the melody. The two music programs utilized rhythmical patterns in 4/4-time signature, teaching children to write musical notes that parallel with $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ fractions, to add these musical notes together to produce fractions, and to solve addition/subtraction problems with musical notes. Transfer of conceptual knowledge and related calculations to trained fractions as well as to untrained fractions (e.g. $\frac{1}{3},\frac{1}{5},\frac{1}{6}$) was tested. The two music groups had higher pre- to post-intervention gains on the overall fraction test scores (although the 'Academic Music' group showed only a trend) and outperformed the comparison group 3- and 6-months post-intervention on the trained fractions test. The 'MusiMath' group, which scored somewhat lower than the other two groups on the untrained fractions pretest, gained more than the comparison group from pre- to post-intervention, and outperformed the comparison group 3- and 6-months post-intervention. These data suggest that the advantage gained in the intervention on the trained fractions by the two music intervention groups, as well as the advantage gained on untrained fractions by the 'MusiMath' group over the comparison group, persisted 3- and 6-months post-intervention.

4.1 | Replication of the 'Academic Music' program

In the current study, we found a positive impact for the replicated 'Academic Music' intervention program presented by Courey et al. (2012). However, there was only a trend toward higher intervention gains than the comparison group. This result replicates the findings reported in Courey et al. (2012).

4.2 | Learning trained fractions in the two intervention groups

The focus of the current study was on comparing the impact of two different music approaches (i.e. acoustic approach and holistic approach) on mathematics achievements. Near transfer was examined by inspecting the ability to parallel musical notations to the corresponding $\frac{1}{2},\frac{1}{4},\frac{1}{8}$ (trianed) fractions. The comparison of the intervention gains in trained fractions test scores indicated that the intervention groups improved more from pre- to post-intervention testing and also outperformed students in the comparison group in the 3- and 6-months post-intervention test.

These findings stress the effectiveness of near transfer. Near transfer from music to closely related math knowledge is frequently attained by constructing music instruction that facilitates an explicit relation between specific mathematical knowledge and properties of musical elements (Jaschke et al., 2013).

4.3 | Learning untrained fractions in the two intervention groups

Far transfer was examined by inspecting the ability to parallel musical notations to fractions with denominators based on division different than 2 (e.g. $\frac{1}{3}, \frac{1}{5}, \frac{1}{6}$), not practiced in the music intervention. The current study compared two different music approaches, the acoustic approach and the holistic approach, hypothesizing that the holistic approach will show greater effects. The comparison of fraction test scores across the three study groups showed that improvement from pre- to post-intervention was more evident in the 'MusiMath' group than in the comparison group, and only students in the 'MusiMath' group outperformed students in the comparison group on the untrained fractions 3- and 6-months post-intervention tests.

It should be noted that the 'MusiMath' group scored somewhat lower than the other two groups at pretest. This may have enabled higher intervention gains. However, the results of the matching procedures as well as controlling for pretest scores at the 3- and 6-month post-intervention analyses verified the advantage of the 'MusiMath' group over the comparison group on untrained fractions test scores.

These findings extend the near transfer results to far transfer and are consistent with previous research suggesting an advantage for music instruction that stresses melody plus rhythm over rhythm only (Dyer et al., 2017; Hallam, 2015; Patscheke & Degé, 2019). The addition of another musical dimension, melody, which conveys additional natural divisions related to the musical form, may have facilitated the far transfer to fractions with denominators based on division different from 2. For example, in the 'MusiMath' group, the students learned Handel's Concerto Grosso Op. 6 No. 7, which contains three melodic sentences. This sample of the Concerto was analyzed as a whole piece, which was divided into three equal parts. The students paralleled the length of the whole piece as $\frac{3}{3}$, in addition to repeatedly attending to the notes' rhythmic values. The math lesson that followed referred to this activity while considering the part-whole concept regarding the fraction.

4.4 | Effectiveness of the intervention programs

In both intervention groups, the gain from pre- to post-intervention in music test scores was correlated with a corresponding gain in the fractions test scores. Scores on the weekly worksheets in music and mathematics were correlated as well. These data suggest that students in the experimental groups demonstrated an ability to represent the conceptual knowledge acquired for music notes in fraction symbols. The music-math interventions explicitly connected rhythmic patterns and fraction concepts, and gave students the ability to implicitly acquire knowledge through repeated experiences in clapping, chanting and drumming rhythmic patterns leading to writing notations that express note values. These activities presumably enhance the generalizability of the part-whole conceptual knowledge (Rittle-Johnson et al., 2001), and are in line with the notion that children learn from experiences that involve combined explicit and implicit learning (Adi-Japha & Karni, 2016; Julius & Adi-Japha, 2016; Nemeth, Janacsek, & Fiser, 2013).

The findings are consistent with previous research supporting music training as improving other nonmusical cognitive and academic skills, especially if the relation between music and mathematics is made explicit (An & Tillman, 2015; Courey et al., 2012; Ribeiro & Santos, 2017). For example, it was found that noninstrumental musical training that used explicit teaching of strategies to recognize musical properties enhanced numerical cognition and comprised a useful tool for rehabilitation of children with low achievements in math (Ribeiro & Santos, 2017). On the other hand, Sala and Gobet's meta-analysis (2017), which focused on instrumental music training, argued that tacit far transfer from music to nonmusic skills was limited and was found only for some cognitive skills (i.e. intelligence and memory) and not for academic skills.

A higher correlation between gain in musical note knowledge and the corresponding fraction knowledge emerged in the 'MusiMath' group versus the 'Academic Music' group. The gain in music test scores was correlated with all post-intervention untrained fractions test scores only in the 'MusiMath' group. It is possible that the larger variability of subdivisions within a musical piece strengthens the conceptual understanding of fractions (Perry, Samuelson, Malloy, & Schiffer, 2010) through greater correspondence between musical and mathematical relations. Specifically, different subdivisions embedded in the rhythm (i.e. $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}$) and the melody (i.e. $\frac{1}{3}, \frac{1}{5}$) may have contributed to the difference.

4.5 | EF and music training

An association between gains in music test scores and measures of inhibitory control emerged in the intervention groups. Inhibitory control in the current study was assessed using the Stroop paradigm that examines interference control (i.e. the ability to ignore irrelevant information). Enhanced tracking of musical beats was found to be associated with better inhibitory control, possibly due to experience with rhythmic activities (e.g. in percussionists, Slater et al., 2017). It may be suggested that children who were better able to keep track of the rhythm learned to write the musical notes more efficiently, and therefore solved note conceptual knowledge and calculation problems better. These findings may also suggest that the association is related to the explicit nature of the mixed music-math instruction in the intervention programs (Zelazo, 2015). No associations emerged between the Trail Making Test and music test scores, possibly because this test is a less sensitive measure than the Stroop task.

It may be suggested that future studies assess EF at post-training as well, to see whether music instruction improves EF scores, similarly to findings concerning music training (Bialystok & DePape, 2009; George & Coch, 2011; Holochwost et al., 2017). For example, Holochwost et al. (2017) found strong evidence of multiple EF benefits from music training, including for inhibitory control and attention flexibility.

Although pretest scores were associated with EF test scores, pre- to post-intervention gains in the fraction test scores of all study groups were not. This finding stresses the importance of repeated practice, whereby the effect of EF decreases with the increase in repetitions (Julius & Adi-Japha, 2015; Lejeune, Catale, Schmitz, Quertemont, & Meulemans, 2013; Roebers & Kauer, 2009). Furthermore, EF did not explain fraction gains even in the intervention groups, possibly because of processes other than sensitivity to rhythmic patterns that are involved in the intervention, for example, the visual-spatial transfer from music duration notes to the spatial representation of fractions. Nevertheless, the possibility remains that other aspects of executive function, not studied here, could better explain transfer effects.

Although EF could not account for the association between the gain in music test scores and post-intervention or 3- and 6-months post-intervention scores of the trained fractions in the intervention groups, EF partially accounted for the association between gains in music test scores and post-intervention scores of untrained fractions. Significant associations after controlling for EF remained only in the 'MusiMath' group for 3- and 6-months post-intervention. The difference between trained and untrained fractions may be related to different mechanisms that underlie their learning in the intervention.

5 | CONCLUSIONS AND LIMITATIONS

In conclusion, the results of the current study demonstrate the potential for using music to teach fraction concepts in the elementary curriculum. Music instruction as an integral part of the elementary curriculum contributes to the conceptual and procedural knowledge of fractions. However, while replicating Courey et al.'s study, it was found that the 'Academic Music' group outperformed the comparison group only on the trained fractions. This finding suggests limitations to transfer of knowledge from integrated music-math lessons to mathematics. Teachers should consider the exact parallels between music and math when designing an integrated program. The findings of the current study support the use of a 'holistic' rather than an 'acoustic' approach, where the former may facilitate a more elaborated transfer (Wiggins & Espeland, 2018).

The conclusions reported here must be considered within the limitations of the study. The sample size was small, pretest scores varied between groups, and all classes were from one elementary school in order to minimize variability. Elementary schools typically include 2–4 classes per age-group, with different degrees of heterogeneity among children within classes. Previous studies examining the effects of music intervention programs on mathematics skills included a similarly small number of participants (An & Tillman, 2015; Courey et al., 2012). Furthermore, the comparison group received the standard curriculum for fractions, but did not receive any other active intervention (i.e. art). This methodology is consistent with recent studies that also utilized a non-active comparison group (An & Tillman, 2015; Courey et al., 2012; Riberio & Santos, 2017). Another methodological caveat is that the two music intervention programs differed in the order in which math topics were covered and in which music was integrated with math. The 'MusiMath' holistic program consisted of integrated lessons throughout the program (12 lessons), while the 'Academic Music' acoustic program had integrated lessons only from mid-program onward (last 6 lessons), which may not have sufficed for full music-math integration, and is a confound on the findings. Despite these limitations, the intervention study provided an opportunity to observe how students' fraction knowledge was developed through learning mathematics integrated with music. Future studies may include more explanatory variables that would elucidate the findings.

CONFLICT OF INTEREST

The authors whose names are listed immediately below certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or nonfinancial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in ["figshare"] at https://doi.org/10.6084/m9.figshare.8203373.v1, reference number [DS-08-18-0411-SI].

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Additional supporting information may be found online in the Supporting Information section at the end of the article.

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