EDUCATIONAL STUDIES
https://doi.org/10.1080/03055698.2023.2216826

# Let me make mathematics and music together: A meta-analysis of the causal role of music interventions on mathematics achievement

Ayça Akın

Department of Software Engineering, Faculty of Engineering, Antalya Belek University, Antalya, Turkey

**ABSTRACT**

This research aims to conduct a fixed-effects meta-analysis to unpack the causal role of music interventions on mathematics achievement. Findings indicated that music interventions had a small to moderate positive effect on mathematics achievement ($N = 77{,}595$, $k = 245$, $g = 0.36$, $p < 0.01$, 95% CI [0.34, 0.38]). Mathematics skills, instructional mathematical content, types of music interventions, and age were significant moderators, whereas development status was not a significant moderator for this meta-analysis. The most crucial result was that studies using music-mathematics integrated intervention produced a large effect size. This study can be considered interesting in terms of revealing that a significantly strong and positive transfer in mathematics learning was only achieved when used mathematics and music together in the learning environment. Consequently, the current research is regarded to have laid some groundwork for further meta-analytic investigations as it provides detailed, up-to-date, and useful evidence on this issue.

**ARTICLE HISTORY**
Received 1 November 2022
Accepted 25 February 2023

**KEYWORDS**
Far transfer; mathematics learning; meta-analytic research; music interventions; music-mathematics integrated intervention

## Introduction

Mathematics and music are the two disciplines that have enhanced and fed one another since ancient times (da Silva 2020). The reason why mathematics and music are closely associated is that these two subjects have many similarities. For example, individuals can express mathematics and music using representational language and symbolic notations. Both disciplines also require reasoning abstractly, thinking quantitatively, and using symbolic notations (Azaryahu and Adi-Japha 2022). Additionally, mathematical concepts such as patterns, ordering, symmetry, numbers, ratios, fractions, division, and the part-whole concept are crucial in the disciplines of mathematics and music (Azaryahu et al. 2020; Yesilkaya, Jelen, and Eskioglu 2021). Similarly, any musical notions such as tempo, rhythm, melodies, and harmonisation can be represented mathematically, and these components are associated with mathematical content standards such as numbers & operations and statistics & probability (e.g. An and Tillman 2015; Azaryahu and Adi-Japha 2022). Complicated musical concepts become clear and understandable thanks to the use

**CONTACT** Ayça Akın aycaakin07@gmail.com Department of Software Engineering, Faculty of Engineering, Antalya Belek University, Antalya, Turkey

of mathematical techniques (Yesilkaya, Jelen, and Eskioglu 2021). The common points of mathematics and music have led researchers to make assumptions about this issue. In the context of mathematical education, there are two main assumptions regarding music. The first is that music has a mathematical basis, as well as mathematics has an aesthetic/artistic structure (Abdounur 2003; cited in da Silva 2020). The other is that music allows being used as an alternative instructional method in mathematics learning and instruction (e.g. Azaryahu and Adi-Japha 2022; Yesilkaya, Jelen, and Eskioglu 2021). Consistent with earlier research findings, it is important to reveal the power of music within the framework of mathematics education at this point.

The majority of past research in this field concentrated on the link between mathematics skills and musical ability. According to the findings of most of these studies, students' musical abilities significantly and positively correlated with their mathematics skills (e.g. Boyd 2013; Vaughn 2000). However, such studies in the context of correlational design did not enable researchers to make solid inferences concerning the causal effectiveness of music on students' mathematics achievement (Román-Caballero et al. 2022). Since it is essential to explain the causal role of music on mathematics achievement, the number of research articles on this topic is steadily growing (Román-Caballero et al. 2022).

Past research revealed that the effectiveness of music interventions on participants' mathematics achievement was investigated from pre-school (PreK-K) to undergraduate (K-16) level (e.g. Anderson and Krasnozhon 2021; Azaryahu and Adi-Japha 2022; Raja and Bhalla 2021; Yesilkaya, Jelen, and Eskioglu 2021). In the context of music interventions, researchers focused on mathematics skills such as arithmetic skills, problem-solving, logical reasoning, and spatial skills (e.g. An and Tillman 2015; Anderson and Krasnozhon 2021; Raja and Bhalla 2021). Additionally, the effects of various music interventions such as instrumental musical intervention, standardised music intervention, and music-mathematics integrated intervention on students' mathematics performance were examined in previous research (e.g. Anderson and Krasnozhon 2021; Azaryahu and Adi-Japha 2022; Raja and Bhalla 2021). The findings of several of these studies indicated that students in the music intervention group improved their mathematical abilities statistically significantly more than those in the neither-intervention group (e.g. Anderson and Krasnozhon 2021; Azaryahu and Adi-Japha 2022; Azaryahu et al. 2020; Raja and Bhalla 2021). Conversely, the findings of some studies revealed that no significant causal effects of music interventions on students' mathematics performance were obtained (e.g. Cheek and Smith 1999; Omniewski 1999). In the context of experimental and quasi-experimental research, previous research concentrating on the effectiveness of music interventions on participants' scholastic or mathematics performance was inconsistent in terms of findings.

Azaryahu and Adi-Japha (2022) emphasised that results regarding the transfer from music interventions to students' mathematics learning were inconclusive. This inconsistency remained unclear when we reviewed recent meta-analytic studies that investigated the causal role of music interventions on students' academic or mathematics performance since most of these studies differed in their findings (e.g. Cooper 2020; Román-Caballero et al. 2022; Sala and Gobet 2017, 2020). The highly heterogeneous meta-analytic data set of these studies involving all papers associated with music interventions that focused not only on mathematics but also on cognition, executive functions, intelligence, literacy, memory, verbal skills, non-verbal skills, and working memory was highly probable to be one of the main sources of uncertainty. The reason for the inconsistent findings of recent meta-analysis papers was associated with the lack of classification in the context of music interventions such as instrumental music intervention, standardised music intervention, and music-mathematics integrated intervention (Román-Caballero et al. 2022). Additionally, to our knowledge, no meta-analysis studies have evaluated the effectiveness of music interventions on mathematics skills, instructional mathematics content, the types of music interventions, and developmental status (i.e. typical developing students, and students with developmental disabilities) separately, nor have these been analysed as potential moderators. Many recent papers have not been included in any past meta-analytic research concentrating on the effectiveness of music interventions on participants' mathematics performance, due to the growing quantity of studies in recent years (e.g. Anderson and Krasnozhon 2021; Azaryahu and Adi-Japha 2022; Azaryahu et al. 2020; Raja and Bhalla 2021; Yesilkaya, Jelen, and Eskioglu 2021). Nonetheless, Román-Caballero et al. (2022) have emphasised that findings from well-structured meta-analytic research still seem to be limited, and further research is needed to make more solid conclusions. Unfortunately, the existing literature did not provide a more in-depth insight into this issue due to ambiguous results on the causal role of music interventions on students' mathematics achievement based on previous studies. Given all the above, it is essential to conduct a new meta-analytic research paper that examines the effectiveness of music interventions on learners' mathematics performance in depth. Consequently, meta-analysis research that investigates the causal role of music interventions on mathematics achievement by considering potential moderators may provide detailed, up-to-date, and beneficial evidence on this subject.

## Potential moderators of the causal role of music interventions on mathematics achievement

According to published research, the causal role of music interventions on mathematics achievement can be identified as mathematics skills, instructional mathematical content, the types of music interventions, age, and developmental status.

### *Mathematics skills*

Mathematics skills are a collection of various skills that are associated with the ability to handle, analyse, evaluate, and store mathematical data (Xie et al. 2020). In the context of music interventions, it was seen that researchers focused on four components of mathematics skills, namely arithmetic skills, problem-solving, spatial skills, and logical reasoning. These were considered crucial components of mathematics skills in previous studies (Fuchs et al. 2015; Lin 2011). Accuracy, flexibility, and fluency related to performing arithmetic operations in the context of irrational numbers, calculus, and statistics, as well as having procedural knowledge are included in the scope of arithmetic skills (Campbell 2004). Several skills such as comparison, deduction, and judging quantitative relationships comprise logical reasoning (Xie et al. 2020). Spatial skills are described as the capacity to create, receive, retain, and transform visual data (Carroll 1993). Moreover, spatial skills consist of various skills such as mental rotation, visualisation, and spatial orientation (e.g. Carroll 1993; Uttal et al. 2013). Obtaining internal representations of quantitative relationships from quantitatively rich contexts and coming up with possible solutions are referred to as problem-solving skills in mathematics (Campbell 2004). Since problem-solving skills are the greatest predictor of mathematics achievement, it is emphasised throughout the mathematics curricula and at all grade levels from preschool through undergraduate education (Fuchs et al. 2015).

The findings of previous research revealed that various music interventions had a positive influence on students' problem-solving, arithmetic skills, logical reasoning, and spatial skills, (e.g. An and Tillman 2015; Anderson and Krasnozhon 2021; Raja and Bhalla 2021). It has been emphasised that music interventions are more beneficial for developing students' arithmetic skills than other components of mathematics skills since music interventions are an integral part of the elementary education curriculum (Azaryahu and Adi-Japha 2022). It is possible to claim that the effectiveness of music interventions on mathematics achievement is larger in the component of arithmetic skills than in other components. As a result, investigating the moderator variables of mathematics skills in the effectiveness of music interventions on mathematics achievement may yield important results on this subject.

### *Instructional mathematics content*

Instructional mathematics content is classified into two categories as foundational mathematical content and higher-level mathematical content (Jitendra et al. 2018). Foundational mathematical content is closely related to the basic mathematical concepts that students need to use in real-world contexts. Basic mathematical concepts such as numbers, four operations, and fractions are considered components of foundational mathematical content (Jitendra et al. 2018). Conversely, higher-level mathematical content relates to complex mathematical concepts that require the use of cognitive skills such as reasoning quantitatively and abstractly. Complex mathematical concepts such as equations, slope, derivative, and integral are the components of high-mathematical content (Jitendra et al. 2018). Based on previous research findings, students benefited from music interventions not only in acquiring foundational content but also in comprehending higher-level mathematical content (e.g. Anderson and Krasnozhon 2021; Azaryahu and Adi-Japha 2022). Unfortunately, it is still unknown if the causal role of music interventions on mathematics achievement differs depending on the categories of instructional mathematics content. For this reason, analysing the moderator role of instructional mathematics content in the effectiveness of music interventions on mathematics achievement may produce critical findings regarding this topic.

### *The types of music interventions*

The effectiveness of various music interventions on students' mathematics achievement was investigated in the literature, including instrumental musical intervention, standardised music intervention (i.e. Kodály and Kindermusik etc.), and music-mathematics integrated intervention (e.g. Anderson and Krasnozhon 2021; Azaryahu and Adi-Japha 2022; Raja and Bhalla 2021). The majority of previous research employed specific music interventions such as instrumental and standardised music interventions with no clear link to mathematics and found limited and inconclusive evidence of transfer (Román-Caballero et al. 2022; Sala and Gobet 2017). Moreover, the results of recent research revealed that the association between school music achievement and mathematics achievement was larger for instrumental music intervention compared to standardised music intervention (Guhn, Emerson, and Gouzouasis 2020). Also, the findings of several studies showed that music-mathematics integrated intervention had a positive transfer effect on students' mathematics achievement (e.g. Azaryahu and Adi-Japha 2022; Yesilkaya, Jelen, and Eskioglu 2021). Therefore, the types of music interventions may moderate the causal role of music intervention on mathematics achievement. It is possible to argue that the effectiveness of the music-mathematics integrated intervention on mathematics achievement is greater than instrumental musical intervention and standardised music intervention. To verify (or refute) this argument, more in-depth studies are needed.

### *Age*

Music interventions were not commonly utilised at the middle, high school, and undergraduate degrees in comparison to the preschool and elementary school levels. Although there has been a growing interest in using music in K-16 education in recent years, previous studies, especially at the undergraduate level, were mostly qualitative and sparse (Anderson and Krasnozhon 2021). Results of many studies revealed that younger children more significantly improved mathematical performance than older children in the context of music interventions (e.g. Harris 2007; Raja and Bhalla 2021). Moreover, the results of the recent research indicated that music interventions had a significant influence on undergraduate students' mathematics performance (Anderson and Krasnozhon 2021). Azaryahu and Adi-Japha (2022) assert that since music interventions are a crucial part of the elementary education curricula, music interventions are more beneficial for developing elementary students' mathematics skills compared to students at other levels of education. To verify (or refute) this argument, more in-depth studies are required.

### *Developmental status*

In the context of music interventions, several studies compared the mathematics skills of individuals with/without developmental disabilities (e.g. Elofsson et al. 2018; Ribeiro and Santos 2017, 2020). The findings of some of these papers revealed that students with typical development improved mathematics skills significantly more than students with developmental disabilities (e.g. Elofsson et al. 2018), whereas the results of other studies revealed that music interventions were a more effective tool for students with lower performance or learning disabilities in mathematics (e.g. Ribeiro and Santos 2017, 2020). Given the ambiguous results on this topic, more research examining the effect sizes of music interventions on mathematics performance regarding developmental status may be beneficial.

## The current research

Based on the literature search, a growing number of meta-analysis studies are being demanded that provide a thorough and detailed viewpoint on the causal role of music interventions on mathematics achievement. Our search of the literature has not yet revealed any research articles focusing on whether and to what extent music intervention is effective in students' mathematics achievement. Moreover, educational researchers (e.g. Anderson and Krasnozhon 2021; Román-Caballero et al. 2022) point out that findings from well-structured meta-analytic research still seem to be limited, and further research is needed to make more solid conclusions regarding the causal role of music interventions on mathematics achievement. As a result, the present research aims to unpack the causal role of music on mathematics achievement by considering moderator variables, namely mathematics skills, instructional mathematical content, the types of music interventions, age (grade level), and developmental status. The following are the research questions in the present research: (1) What is the overall effect of music interventions on mathematics achievement? (2) Do the effect sizes of music interventions on mathematics achievement differ significantly when potential moderators are considered?

## Method

The meta-analytic design has been utilised in this study to unpack the causal role of music interventions on mathematics achievement by considering potential moderators. In the framework of meta-analysis studies, the findings of many independent research papers on a certain topic are thoroughly gathered, then these results are merged and integrated, and ultimately the integrated data are statistically analysed (Borenstein et al. 2009). Additionally, meta-analytic designed studies allow for a quantitative evaluation of previous research and produce more thorough and comprehensive conclusions due to increased statistical power (Román-Caballero et al. 2022).

### *Systematic search strategies*

The most popular databases namely ERIC, Google Scholar, ProQuest Dissertations & Theses, PsycINFO, ScienceDirect, Scopus, and Web of Science were used to perform a systematic search of the literature. The terms "music", "music intervention", "music instruction", "music training "music-mathematics", "mathematics-music", and "music-maths integrated" were searched along with "maths", "mathematics, "arithmetic", "spatial", "logical" and "problem-solving" for the years between 1975 and October 2022. The seven criteria given below have to be satisfied for any study to be considered for inclusion in this meta-analysis.

(i) The research papers had to be published between 1975 and October 2022.
(ii) The experimental or quasi-experimental design required to be used in the studies.
(iii) The necessary information was available to determine each study's effect size.
(iv) Studies had to investigate students' mathematics achievement within the scope of music interventions.
(v) One of the outcome variables had clearly to be associated with K-16 students' mathematics achievement performance.
(vi) A non-music intervention or an untrained class had to be regarded for the control/comparison group in the study.
(vii) Research papers had to be written in English.

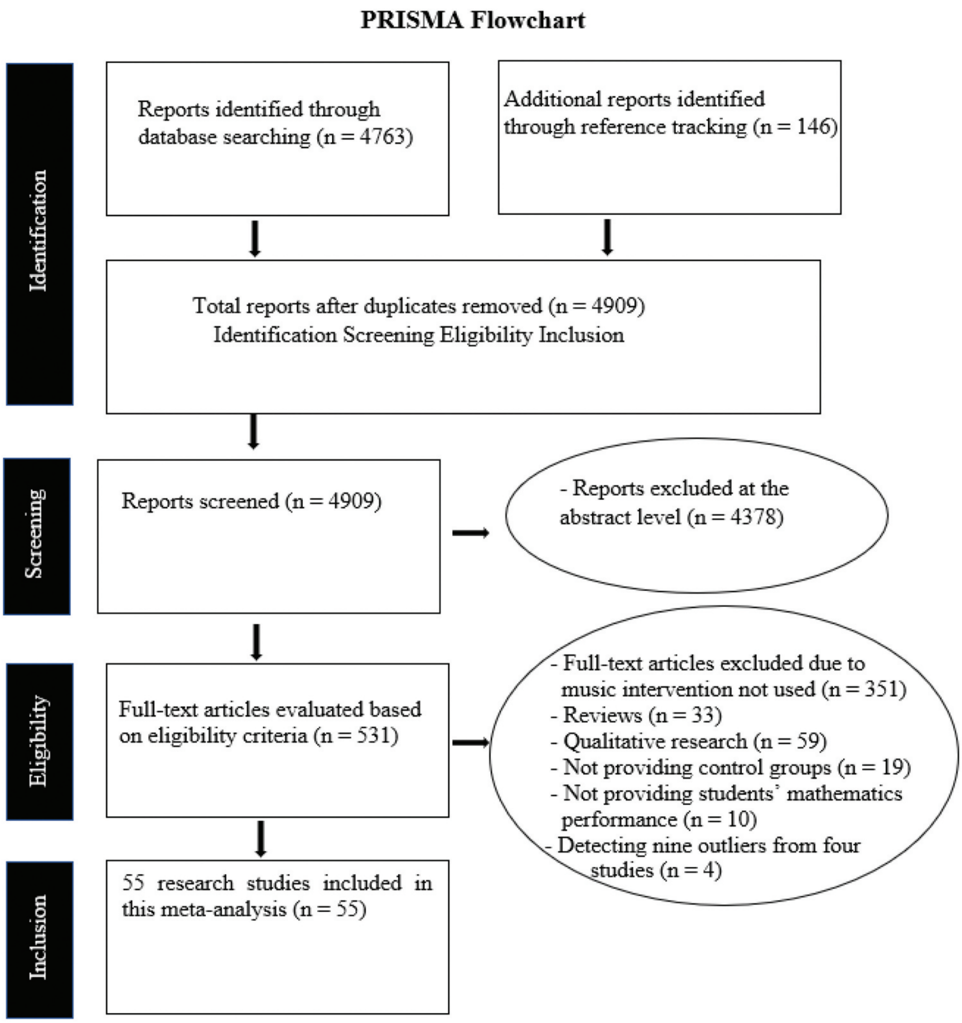


Figure 1. The systematic search process of research paper selection based on the PRISMA guidelines.

Since the PRISMA meta-analysis guidelines, systematic search strategies were carried out (Moher et al. 2009). Consequently, 55 research publications met the inclusion requirements in the framework of this meta-analytic study (see Figure 1).

## Coding process

To unpack the causal role of music interventions on mathematics achievement, a list of moderator variables was identified based on previous research. For the coding process, a comprehensive coding form was created to extract the necessary details from each research paper. This form covered the research identification label, the components of mathematics skills (i.e. arithmetic skills, logical reasoning, spatial skills, and problem-solving), the elements of instructional mathematical content (i.e. foundational mathematical content and higher mathematical content), the types of music interventions (i.e.

instrumental musical intervention, standardised music intervention, and music-mathematics integrated intervention), age (i.e. from kindergarten to undergraduate level), developmental status (i.e. students with typical developing, and students with developmental disabilities), and statistical measures (e.g. *n*, *M*, and *SD*) to quantify the effect size of each research paper concerning the causal role of music interventions on students' mathematics achievement. Furthermore, eligible papers were individually coded by two researchers, yielding a kappa of .962, demonstrating a virtually excellent agreement based on the criteria of Landis and Koch (1977).

## Data analysis

In this meta-analytic research, Hedges's *g* was used as a measure of effect size for each research to show the causal role of music interventions on mathematical achievement. After adjusting for pre-tests as well as some other covariates, the difference between the post-tests of the intervention and control groups was divided by the pooled standard deviation to compute effect sizes, and then to adjust for the sample size, the Hedges' *g* correction was applied to all effect sizes (Borenstein et al. 2009). As a result, adjusted effect sizes were computed utilising either the means of gain scores (i.e. post-pre-test change scores) and the pooled pre-test standard deviations or covariance-adjusted means and unadjusted standard deviations (Jitendra et al. 2018). Unadjusted effect sizes were calculated for nine studies that simply indicated the intervention and control groups' mean post-test scores, standard deviations, and sample sizes, ignoring other variables that could have influenced the outcomes. Moreover, there were no means and standard deviations provided in seven studies, thus the effect sizes of Hedges' *g* were estimated using F statistics, as recommended by Lipsey and Wilson (2001). The effect sizes of group designs were characterised as 0.00 to 0.20 = negligible, 0.20 to 0.50 = moderate, 0.50 to 0.80 = large, and greater than 0.80 = huge (Cohen 1988).

In this meta-analytic research, statistical independence was considered. In the context of music interventions, the majority of studies employed multiple measures of mathematics skills. Some studies were coded as two or three individual studies, each with its own sample of participants. Based on the suggestion of Bijmolt and Pieters (2001), more than one effect size was extracted from studies regarding different components of mathematics skills or a different individual sample since statistical independence violations have little to no impact on confidence intervals (CI), means, and standard deviations for meta-analytic studies. Therefore, any effect size was regarded as a separate outcome instead of nested data in the context of this meta-analysis (Cooper 2020).

Many researchers state that the selection between the models is determined by the extent of heterogeneity among research studies (Card 2012). On the contrary, Borenstein et al. (2014) emphasise that the use of a fixed or random-effects model should be dependent on the researcher's goals and intentions. The methodological approaches of the studies examined in this meta-analysis were similar, each research was planned and implemented similar procedures regarding scientific and methodological approaches, and each research focus on participants' mathematics achievement in the context of music interventions. Following the recommendations of Borenstein et al. (2014) and Cooper (2020), the fixed effects model was the chosen approach for meta-analysis. Additionally, subgroups/moderator analysis and meta-regression analysis were carried out to scrutinise the possible sources of heterogeneity between the effect sizes across studies using the Q-between-groups test (Guler et al. 2022).

To investigate sensitivity analysis and publication bias, outlier analysis was performed first to exclude studies causing publication bias, and then a funnel plot, Egger's regression test, and Duval and Tweedie's trim-and-fill (DTEK) test were utilised to identify possible publication bias (Borenstein et al. 2009; Duval and Tweedie 2000; Egger et al. 1997). A fail-safe N test (FSN) and Orwin's fail-safe N (FSN) test were also provided to assess possible publication bias (Borenstein et al. 2009; Mullen, Muellerleile, and Bryant 2001). The Comprehensive Meta-analysis (CMA) and JASP software were used to perform all statistical analyses regarding this meta-analytic research (Borenstein et al. 2014; JASP 2022).

## Results

### *Sensitivity analysis*

To detect outliers in the data, a sensitivity analysis was conducted (Cooper 2020). To achieve this goal, it was investigated how many studies with a *z*-score greater than 3.0 were included in this meta-analytic data set (Guler et al. 2022). Thus, nine outliers from 6 studies that met this criterion were found (see Figure 1). To provide the reliability of the findings, the final meta-analysis was carried out after the exclusion of nine outliers.

### *Systematic search results*

The final meta-analysis comprised a total of 55 research with 245 effect sizes to clarify the causal role of music interventions on mathematics achievement. The sample sizes from these studies varied between 6 to 12,160 students, and the pooled sample size was 77,595 in this meta-analytic study. Table 1 presents in detail the descriptive features of the final meta-analysis concerning moderator variables.

**Table 1.** Details of the final data set.

| Moderator variables | *f* | % |
|---|---|---|
| **Mathematics skills** | | |
| Arithmetic skills | 89 | 36.3 |
| Spatial skills | 92 | 37.5 |
| Logical reasoning | 32 | 13.1 |
| Problem solving | 32 | 13.1 |
| **Instructional mathematics content** | | |
| Foundational mathematical content | 153 | 62.4 |
| Higher-level mathematical content | 92 | 37.6 |
| **Music interventions** | | |
| Standardized musical intervention | 119 | 48.6 |
| Instrumental music intervention | 95 | 38.8 |
| Music-mathematics integrated intervention | 31 | 12.6 |
| **Age** | | |
| Pre-school | 109 | 44.5 |
| Elementary | 73 | 29.8 |
| Middle | 34 | 13.9 |
| High | 21 | 8.6 |
| Undergraduate | 8 | 3.2 |
| **Developmental status** | | |
| Typically developing students | 231 | 94.3 |
| Students with developmental disabilities | 14 | 5.7 |

## The main effect size of music interventions on mathematics achievement

Of the 245 overall effect sizes, 241 studies yielded in the positive direction, and four studies yielded in exactly 0 direction, revealing no clear effects. A fixed-effects model (FEML) of 245 effect sizes with 77,595 students yielded the overall effect size of $g = 0.36$, $SE = 0.009$, $p < 0.001$, 95% CI [0.34, 0.38]. Moreover, the effect sizes of this meta-analysis ranged from 0.00 to 2.77. The main effect size of music interventions on mathematics achievement was $g = 0.36$, $p < 0.01$ revealing a statistically significant and small to moderate effect size, following Cohen's (1988) criteria. Moreover, the existence of potential moderators was confirmed by the test for heterogeneity, $Q(df = 240) = 2062.95$, $p = 0.001$, and $I^2 = 88.36\%$ based on the suggestion of Lipsey and Wilson (2001).

## Findings of moderator analyses

Moderator analyses indicated the mean effect sizes significantly differed by mathematics skills ($Q_b(3) = 10.59$, $p < 0.05$); instructional mathematical content ($Q_b(1) = 25.14$, $p < 0.01$); types of music interventions ($Q_b(2) = 230.62$, $p < 0.01$); and age ($Q_b(4) = 33.87$, $p < 0.01$). On the other hand, the findings by developmental status indicated no significant difference ($Q_b(1) = .38(1)$, $p > 0.05$) between the mean effect size estimate for typically developing students ($g = 0.36$, $p < 0.01$) and that for students with developmental disabilities ($g = 0.43$, $p < .05$). Table 2 showed a list of all mean effect sizes related to potential moderators, along with k, 95% CI, and $Q_b$.

Regarding mathematics skills, arithmetic skills yielded a moderate effect size ($g = 0.47$, $p < 0.01$) whereas the mean effect size estimate for spatial skills, logical reasoning, and problem-solving were $g = 0.36$, $p < 0.01$; $g = 0.34$, $p < 0.01$; and $g = 0.36$, $p < 0.01$, respectively revealing a small to moderate positive effect. According to meta-regression analyses, the mean effect size for arithmetic skills was significantly greater than spatial skills ($\beta = -0.11$, $z = -2.15$, $p < 0.05$), logical reasoning ($\beta = -0.13$, $z = -2.37$, $p < 0.01$), and

Table 2. Analyses for moderator variables of effect sizes regarding the FEML.

| Moderator variables | *k* | *g* | *g* (95%CI) | $Q_b$ (df) |
|---|---|---|---|---|
| **Mathematics skills** | | | | 10.59*(3) |
| Arithmetic skills | 89 | 0.47** | [0.40, 0.54] | |
| Spatial skills | 92 | 0.36** | [0.30, 0.42] | |
| Logical reasoning | 32 | 0.34** | [0.27, 0.41] | |
| Problem solving | 32 | 0.36** | [0.34, 0.38] | |
| **Instructional mathematics content** | | | | 25.14**(1) |
| Foundational mathematical content | 153 | 0.46** | [0.42, 0.50] | |
| Higher-level mathematical content | 92 | 0.34** | [0.32, 0.36] | |
| **Music intervention** | | | | 230.62**(2) |
| Standardized musical intervention | 119 | 0.23** | [0.20, 0.26] | |
| Instrumental music intervention | 95 | 0.49** | [0.46, 0.51] | |
| Music-mathematics integrated intervention | 31 | 0.61** | [0.51, 0.71] | |
| **Age** | | | | 33.87**(4) |
| Pre-school | 109 | 0.40** | [0.34, 0.46] | |
| Elementary | 73 | 0.47** | [0.42, 0.52] | |
| Middle | 34 | 0.36** | [0.34, 0.38] | |
| High | 21 | 0.31** | [0.28, 0.34] | |
| Undergraduate | 8 | 0.19* | [−0.03, 0.41] | |
| **Developmental status** | | | | |
| Typically developing students | 231 | 0.36** | [0.34, 0.38] | .38(1) |
| Students with developmental disabilities | 14 | 0.43* | [0.21, 0.65] | |

problem-solving ($\beta = -0.11$, $z = -2.17$, $p < 0.01$). Concerning instructional mathematics content, foundational mathematical content yielded a moderate effect size ($g = 0.46$, $p < 0.01$), while higher-level mathematical content yielded a small to moderate positive effect size ($g = 0.34$, $p < 0.01$). The mean effect size for foundational mathematical content was significantly larger than for higher-level mathematical content ($\beta = -0.12$, $z = -2.29$, $p < 0.01$) based on meta-regression analyses.

Concerning music interventions, studies using standardised musical intervention produced a small to moderate positive effect size ($g = 0.23$, $p < 0.01$), and studies using instrumental music intervention yielded a moderate effect size ($g = 0.49$, $p < 0.01$), whereas studies using music-mathematics integrated intervention produced a large effect size ($g = 0.61$, $p < 0.01$). According to meta-regression analyses, the mean effect size for music-mathematics integrated intervention was significantly greater than for instrumental music intervention ($\beta = -0.39$, $z = -7.28$, $p < 0.01$), and that for standardised musical intervention ($\beta = -0.12$, $z = -2.28$, $p < 0.01$). Additionally, the mean effect size for instrumental music intervention was significantly greater for standardised musical intervention ($\beta = -0.26$, $z = -5.23$, $p < 0.01$).

Regarding age, studies focusing on preschool and elementary school students produced moderate effect sizes ($g = 0.40$ and 0.47, $p < 0.01$ respectively) and studies focusing on middle and high school students produced small to moderate positive effect sizes ($g = 0.36$ and 0.31, $p < 0.01$ respectively), whereas studies focusing on undergraduate students yielded a small effect size ($g = 0.19$, $p < 0.05$). The mean effect size for studies focusing on elementary students was significantly greater than for studies focusing on middle ($\beta = -0.11$, $z = -2.18$, $p < 0.01$), high ($\beta = -0.16$, $z = -2.48$, $p < 0.01$), and undergraduate students ($\beta = -0.28$, $z = -5.39$, $p < 0.01$) based on meta-regression analyses.

### *Publication bias*

To investigate publication bias, the analysis of funnel plot, Egger's regression test, and DTEK test were primarily utilised in this meta-analysis. Figure 2 demonstrated an acceptable level of symmetry through the analysis of the funnel plot. No publication bias was observed based on the findings of Egger's regression test ($t = 1.46$, $p = 0.14$). The DTEK test did not reveal any difference between the observed value ($g = .36$) and the adjusted value ($g = 0.36$) in the context of a fixed-effects model. Considering the equation of Mullen, Muellerleile, and Bryant (2001), 5.87 studies were needed to eliminate the significant effect at $p > 0.05$ through the analysis of the FSN test for this meta-analytic research. Moreover, 8480 missing studies would require reducing the main effect size to a negligible effect, as determined by Orwin's FSN test. As a result, any effect seen in the current meta-analytic research was improbable to be related to publication bias.

## Discussion

### *General overview of the causal effect of music interventions on students' mathematics achievement*

To elucidate the causal role of music interventions on mathematics achievement, a total of 55 research with 245 effect sizes were included in the present study. According to

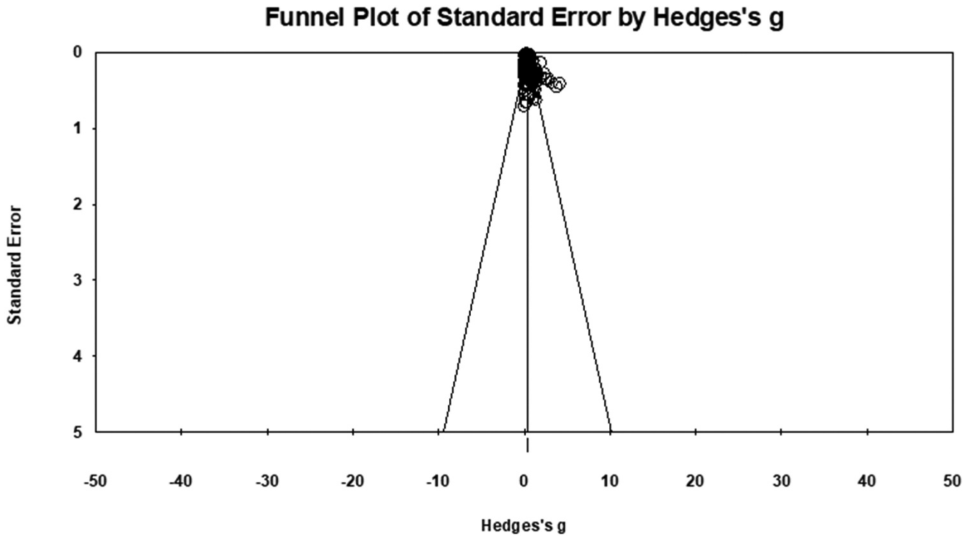


**Figure 2.** Funnel plot of this meta-analytic research.

Cohen's criteria (Cohen 1988), music interventions had a small to moderate positive effect on students' mathematics achievement ($g = 0.36$, $p < 0.01$). Approximately 66% of students in the music interventions group performed significantly better than those in the control group (Coe 2002). In the context of meta-analytic research, this finding generally coincided with the findings of past studies concerning the effectiveness of music interventions on cognitive and scholastic outcomes (e.g. Román-Caballero et al. 2022; Sala and Gobet 2020). Moreover, the main effect size of the current study was somewhat greater than when compared to the findings of past studies such as Cooper (2020) with $g = 0.28$, Román-Caballero et al. (2022) with $g = 0.24$, and Sala and Gobet (2020) with $g = 0.20$ revealing small to negligible or small to moderate positive effect sizes. This difference can be explained by the current research focusing solely on mathematics achievement rather than considering academic and cognitive outcomes together, as well as the rising popularity of music intervention or music-mathematics integrated intervention on individuals' mathematics performance in the past couple of years (e.g. Anderson and Krasnozhon 2021; Azaryahu and Adi-Japha 2022; Azaryahu et al. 2020; Raja and Bhalla 2021; Yesilkaya, Jelen, and Eskioglu 2021).

The results of this meta-analytic study revealed that music interventions had a significantly small to moderate positive effect on mathematics achievement when compared to the control/comparison group. The finding is consistent with many other studies (e.g. An and Tillman 2015; Anderson and Krasnozhon 2021; Azaryahu and Adi-Japha 2022; Azaryahu et al. 2020; Raja and Bhalla 2021) revealing that students in the music intervention group displayed significant improvements in mathematics achievement when compared to those in the control group. Conversely, some studies (e.g. Cheek and Smith 1999; Omniewski 1999) found no significant difference in mathematics achievement between students in the music interventions group and those in the control/comparison group. At this point, the findings of this study are not consistent with the results of some research.

## The role of moderators in the present meta-analysis

### *The role of mathematics skills as a moderator*

Regarding mathematics skills, arithmetic skills yielded a moderate effect size while spatial skills, logical reasoning, and problem-solving produced small to moderate effect sizes (Cohen 1988). The mean effect size obtained for arithmetic skills was significantly larger than for spatial skills, logical reasoning, and problem-solving, which is consistent with the research hypothesis regarding mathematics skills. This finding can be clarified by the elementary school curriculum framework. Mathematical concepts regarding arithmetic skills such as numbers, ratios, fractions, division, and the part-whole concept are essential for the disciplines of mathematics and music within the scope of the elementary education curriculum (Azaryahu et al. 2020; Yesilkaya, Jelen, and Eskioglu 2021). This finding also supports Azaryahu and Adi-Japha's (2022) hypothesis that music interventions are more effective for strengthening children's arithmetic skills than other components of mathematics skills since music interventions are a fundamental part of the elementary education curriculum. Moreover, the findings of a recent study indicated that children benefited more from methods that include aesthetic learning processes such as music interventions when teaching basic arithmetic concepts (Elofsson et al. 2018).

### *The role of instructional mathematics content as a moderator*

Concerning instructional mathematics content, the mean effect size obtained for foundational mathematical content was significantly greater than for higher-level mathematical content. The findings of the current study revealed that foundational mathematical content produced a moderate effect size, whereas higher-level mathematical content yielded a small to moderate effect size (Cohen 1988). The nature of mathematics and music disciplines in the context of the school curriculum can elucidate this result. Foundational mathematical content includes basic mathematical concepts such as numbers, ratios, fractions, division, and the part-whole concept (Jitendra et al. 2018). These concepts are directly linked with musical concepts such as time signatures, beats, rhythm, and melody taught at the elementary school level (Azaryahu et al. 2020; Yesilkaya, Jelen, and Eskioglu 2021). Likewise, these musical concepts are directly associated with mathematics teaching as they can be represented mathematically at the elementary school level. Azaryahu et al. (2020) have emphasised that music teaching as an essential element of the elementary school curriculum helps children learn mathematics. As a result, this finding is not unexpected considering the linkage between mathematics and music at the elementary school level.

### *The role of music intervention types as a moderator*

Based on Cohen's (1988) criteria, studies using music-mathematics integrated intervention yielded a large effect size, while studies using standardised musical intervention yielded a small to moderate effect size and studies using instrumental music intervention produced a moderate effect size. The mean effect size obtained for research using music-mathematics integrated intervention was significantly greater than for studies using standardised musical intervention and instrumental music intervention. Additionally, the mean effect size obtained for studies using instrumental music intervention was significantly greater than for studies utilising the standardised musical intervention. The finding was in line with the finding of the recent research revealing that the relation between school music achievement and mathematics achievement was significantly larger for instrumental music intervention compared to standardised music intervention (Guhn, Emerson, and Gouzouasis 2020). This finding coincided with the findings of some research indicating the significantly positive transfer effect on participants' mathematics performance was obtained in the context of music-mathematics integrated intervention (e.g. Azaryahu and Adi-Japha 2022; Yesilkaya, Jelen, and Eskioglu 2021).

### The role of age as a moderator

Regarding age, studies at preschool and elementary school levels yielded moderate effect sizes, and studies at the middle and high school levels yielded small to moderate effect sizes, while studies at the undergraduate levels yielded a small effect size (Cohen 1988). The mean effect size obtained for studies at elementary school was significantly larger than for studies at middle, high, and undergraduate levels. The result coincided with the findings of many research revealing younger children more significantly improved mathematical performance than older children when given a music intervention (e.g. Harris 2007; Raja and Bhalla 2021). Moreover, the result supported the assertion of Azaryahu and Adi-Japha (2022) that music interventions are more beneficial for developing elementary students' mathematics skills compared to students at other levels of education. In conclusion, this finding is not unexpected since music interventions are an essential part of the elementary education curriculum, and mathematics and music are interrelated subjects when considering the elementary school curriculum (Azaryahu and Adi-Japha 2022; Yesilkaya, Jelen, and Eskioglu 2021).

### The role of developmental status as a moderator

Concerning developmental status, findings indicated a small to moderate effect size for typically developing students whereas a moderate effect size was obtained for students with developmental disabilities. However, there was no statistically significant difference in means for the variables of developmental status. The finding is consistent with the results of some research revealing that students with typical development improve mathematics skills significantly more than students with developmental disabilities (e.g. Elofsson et al. 2018). Moreover, this finding does not coincide with the other past studies indicating that music interventions were a more effective tool for students with lower performance in mathematics (e.g. Ribeiro and Santos 2017, 2020). In conclusion, this finding is unexpected in terms of the results of past research.

## Limitations and guidelines for further studies

Due to the nature of meta-analysis studies, the current research has several limitations. One of them is that there are possible limitations to generalisation results obtained from a small set of experimental or quasi-experimental research (Jitendra et al. 2018). Although a comprehensive search strategy has been used in this study, only 55 studies have been found in the last 47 years that focus on the causal role of music interventions on mathematics achievement. The total number of studies included in this meta-analytic research is comparatively larger or equal compared to intervention studies for cognitive skills, affective factors such as anxiety, motivation, and stress, and other academic fields (e.g. Cooper 2020; Román-Caballero et al. 2022). It is suggested that the findings of moderator analyses may be impacted by a limited number of studies, despite the fact that this meta-analysis included a moderate number of studies (Hedges and Pigott 2004). For this reason, it is recommended to incorporate a high number of studies in meta-analysis studies. Conversely, the number of studies focusing on the causal role of musical interventions on mathematics achievement has increased in the last decade. Therefore, this study makes it clear that the literature needs future studies that will provide evidence regarding the causal role of musical interventions on mathematics achievement. Because it is crucial for researchers to conduct more studies on this subject to reach the data saturation of further meta-analysis studies.

The literature search strategy is considered one of the most powerful features of meta-analytic research. However, the literature search strategy may bring some limitations. In the context of the literature search strategy, although many keywords were searched together in this research, some publications may not have been included in this meta-analysis due to specific terms/words associated with music and mathematics such as Carabo-Cone, Dalcroze, Kodály, and Orff Schulwerk methods and rotation skills, estimation skills, orientation skills, and visual reasoning. Therefore, it can be argued that the second limitation of this study is related to the literature search strategy.

Since the studies considered in this analysis are experimental or quasi-experimental, eliminating naturalistic observational studies is the third limitation of the current study (Zhang and Zhu 2022). For this reason, it is suggested that more detailed findings can be obtained by considering more naturalistic observational studies, making a more systematic review, and analysing them in depth in further studies. A fourth limitation is that eight research of undergraduate participants satisfied the inclusion criteria of this research. Similarly, only 14 studies of participants with developmental disability issues satisfied the inclusion criteria of this research. Due to the fact that the number of effect sizes in the moderators' analyzes were small in some cases (e.g. undergraduate students and with developmental disabilities), this situation might be an additional limitation of this study. Estimates of the causal influence of music interventions on mathematics achievement are less clear due to the small effect sizes for these moderators. To provide more clear evidence for further studies focusing on the causal role of musical interventions on mathematics achievement, more research needs to be carried out with undergraduate students and students with developmental disabilities.

Due to the lack of adequate data in this meta-analysis, the role of moderators such as gender, socio-economic status, type of mathematical topics (e.g. equation, fraction, and function), and intervention period could not be examined. It may be recommended to unpack the causal role of music interventions on mathematics achievement by also including different moderators such as gender, socio-economic status, and intervention period in future meta-analysis studies that contain sufficient data related to the above-mentioned moderators. For this reason, it can be asserted that by conducting more experimental or quasi-experimental studies on this topic by considering different moderator variables (e.g. gender, socio-economic status, and type of mathematical topic) more convincing findings can be obtained in the future. Consequently, more testing and analysis of these moderators need to be carried out in further research.

## Conclusion

The current study aims to give an overview of results related to the causal role of music interventions on mathematics achievement, as well as to investigate moderator variables in this context. Findings indicated that music interventions had a small to moderate positive effect on students' mathematics achievement. Mathematics skills, instructional mathematical content, types of music interventions, and age significantly moderated the causal role of music intervention on mathematics achievement, whereas development status was not a significant moderator for this topic.

In the context of the current research, the reason why music interventions had a small to moderate positive effect on students' mathematics achievement might be related to the near and far transfer in learning. The near transfer is the transfer of learning/skills in the same area, which is occasionally seen, whereas far transfer is the transfer of learning/skills through two different areas that are unusual or probably not seen (Sala and Gobet 2020). Since this study failed to show that music interventions had a significantly strong effect on mathematics achievement in terms of effect size, it could not be argued that far transfer in mathematics learning occurs with music interventions. On the other hand, the results of this research revealed that studies using music-mathematics integrated intervention yielded a large effect size, while studies using standardised musical intervention yielded a small to moderate effect size and studies using instrumental music intervention produced a moderate effect size. Even though this result is consistent with many past studies suggesting an extremely rare occurrence of far transfer in learning (e.g. Cooper 2020; Román-Caballero et al. 2022; Sala and Gobet 2020), this study can be considered interesting in terms of revealing that a significant strong and positive transfer in mathematics learning is only achieved when used mathematics and music together in the learning environment. Therefore, it can be put forward that a significantly strong and positive far transfer in mathematics learning occurs with music-mathematics integrated intervention.

Sala and Gobet (2017) have emphasised that the causal role of music on mathematics learning or outputs is still not fully answered owing to a paucity of well-planned studies in the context of music and mathematics integration. Given the importance of interdisciplinary studies, it will be useful for expert researchers to provide concrete opportunities for both mathematics/music teachers and novice scholars to conduct well-designed studies in terms of music-mathematics integrated intervention. Moreover, it is possible to claim that using a sufficient number of well-designed in this context can lead to higher mathematics achievement, thus producing greater effect sizes for future meta-analytic studies.

The current research is regarded to have laid some groundwork for further meta-analytic investigations as it provides detailed, up-to-date, and useful evidence on the causal role of music on mathematics achievement. On the other hand, it can be argued that this area of research still has an uncertain and intriguing structure after this meta-analysis. Due to the lack of adequate data in terms of different moderators (e.g. gender, socio-economic status, and type of mathematical topic), these variables were not included in this meta-analysis. As more articles are released in this area, it would be wise to revisit and analyse the data by including more specific moderators, such as gender, socio-economic status, types of mathematics topics, etc. Consequently, we urge academics to continue to carry out comprehensive and well-planned studies that will give solid evidence regarding effective interventions in the context of music and mathematics integration.

## Acknowledgements

The author(s) received no financial support for the research, authorship, and/or publication of this article.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Notes on contributor

Dr ***Ayça Akın*** is a Doctor in Republic of Turkey Ministry of National Education in Turkey, who mainly focuses on the study of mathematics education, measurement and evaluation in mathematics education, mathematical reasoning, and international and comparative education in mathematics.

## ORCID

Ayça Akın http://orcid.org/0000-0002-6107-3487

## References

Abdounur, O. J. 2003. *Mathematics and music: Analogic thinking in meaning construction*. Sao Paulo: Escrituras Editora.

Anderson, J. L., and L. A. Krasnozhon. 2021. "Effect of the Use of Music on Definitional Knowledge in an Introductory Statistics Course: Evidence from a Pareto Chart Activity." *Decision Sciences Journal of Innovative Education* 19 (4): 265–274. doi:10.1111/dsji.12237.

An, S. A., and D. A. Tillman. 2015. "Music Activities as a Meaningful Context for Teaching Elementary Students Mathematics: A Quasi-Experiment Time Series Design with Random Assigned Control Group." *European Journal of Science and Mathematics Education* 3 (1): 45–60. doi:10.30935/scimath/9420.

Azaryahu, L., and E. Adi-Japha. 2022. ""MusiMath" - a Music-Based Intervention Program for Learning Patterns and Symmetry." *The Journal of Experimental Education* 90 (2): 319–343. doi:10.1080/00220973.2020.1799316.

Azaryahu, L., S. J. Courey, R. Elkoshi, and E. Adi-japha. 2020. "Musimath and Academic Music–Two Music-based Intervention Programs for Fractions Learning in Fourth Grade Students." *Developmental Science* 23 (4): 1–17. doi:10.1111/desc.12882.

Bijmolt, T. H., and R. G. Pieters. 2001. "Meta-Analysis in Marketing When Studies Contain Multiple Measurements." *Marketing Letters* 12 (2): 157–169. doi:10.1023/A:1011117103381.

Borenstein, M., L. V. Hedges, J. P. T. Higgins, and H. R. Rothstein. 2009. *Introduction to Meta-Analysis*. New Jersey: Wiley-Blackwell.

Borenstein, M., L. V. Hedges, J. P. T. Higgins, and H. R. Rothstein. 2014. Comprehensive Meta-Analysis *(Version 3.3.070)*. Englewood, NJ: Biostat.

Boyd, J. R. 2013. *"The Relationship Between Music Participation and Mathematics Achievement in Middle School Students."* Unpublished dissertation, Liberty University, Virginia, US.

Campbell, J. I. D. 2004. *Handbook of Mathematical Cognition*. New York: Psychology Press.

Card, N. A. 2012. *Applied Meta-Analysis for Social Science Research*. New York, NY: Guilford.

Carroll, J. B. 1993. *Human Cognitive Abilities: A Survey of Factor-Analytic Studies*. Cambridge: Cambridge University Press.

Cheek, J. M., and L. R. Smith. 1999. "Music Training and Mathematics Achievement." *Adolescence* 34 (136): 759.

Coe, R. 2002. *It's the Effect Size, Stupid*. Exeter, UK: British Educational Research Association, University of Exeter. http://www.leeds.ac.uk/educol/documents/00002182.htm.

Cohen, J. 1988. *Statistical Power Analysis for the Behavioral Sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Cooper, P. K. 2020. "It's All in Your Head: A Meta-Analysis on the Effects of Music Training on Cognitive Measures in Schoolchildren." *International Journal of Music Education* 38 (3): 321–336. doi:10.1177/0255761419881495.

da Silva, R. S. R. 2020. "On Music Production in Mathematics Teacher Education as an Aesthetic Experience." *ZDM* 52 (5): 973–987. doi:10.1007/s11858-019-01107-y.

Duval, S., and R. Tweedie. 2000. "Trim and Fill: A Simple Funnel-Plot–based Method of Testing and Adjusting for Publication Bias in Meta-analysis." *Biometrics* 56 (2): 455–463. doi:10.1111/j.0006-341X.2000.00455.x.

Egger, M., G. D. Smith, M. Schneider, and C. Minder. 1997. "Bias in Meta-Analysis Detected by a Simple Graphical Test." *BMJ* 315 (7109): 629–634. doi:10.1136/bmj.315.7109.629.

Elofsson, J., A. Englund-Bohm, C. Jeppsson, and J. Samuelsson. 2018. "Physical Activity and Music to Support Pre-School Children's Mathematics Learning." *Education 3-13* 46 (5): 483–493. doi:10.1080/03004279.2016.1273250.

Fuchs, L. S., D. Fuchs, D. L. Compton, C. L. Hamlett, and A. Y. Wang. 2015. "Is Word-Problem Solving a Form of Text Comprehension?" *Scientific Studies of Reading* 19 (3): 204–223.

Guhn, M., S. D. Emerson, and P. Gouzouasis. 2020. "A Population-Level Analysis of Associations Between School Music Participation and Academic Achievement." *Journal of Educational Psychology* 112 (2): 308–328.

Guler, M., S. O. Butuner, S. Danisman, and K. Gursoy. 2022. "A Meta-Analysis of the Impact of Mobile Learning on Mathematics Achievement." *Education and Information Technologies* 27 (2): 1725–1745. doi:10.1007/s10639-021-10640-x.

Harris, M. A. 2007. "Differences in Mathematics Scores Between Students Who Receive Traditional Montessori Instruction and Students Who Receive Music Enriched Montessori Instruction." *Journal for Learning Through the Arts* 3 (1): 1–50. doi:10.21977/D93110059.

Hedges, L. V., and T. D. Pigott. 2004. "The Power of Statistical Tests for Moderators in Meta-Analysis." *Psychological Methods* 9 (4): 426–445. doi:10.1037/1082-989X.9.4.426.

JASP, T. 2022. "JASP (Version 0.16)." https://jaspstats.org.

Jitendra, A. K., A. E. Lein, S. H. Im, A. A. Alghamdi, S. B. Hefte, and J. Mouanoutoua. 2018. "Mathematical Interventions for Secondary Students with Learning Disabilities and Mathematics Difficulties: A Meta-Analysis." *Exceptional Children* 84 (2): 177–196. doi:10.1177/0014402917737467.

Landis, J. R., and G. G. Koch. 1977. "The Measurement of Observer Agreement for Categorical Data." *Biometrics* 33 (1): 159–174. doi:10.2307/2529310.

Lin, C. 2011. *The Development of Intelligence and Mathematical Learning*. Beijing: China Light Industry Press.

Lipsey, M. W., and D. B. Wilson. 2001. *Practical Meta-Analysis*. Thousand Oaks: SAGE.

Moher, D., A. Liberati, J. Tetzlaff, D. G. Altman, and P. Group. 2009. "Reprint—Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement." *Physical Therapy* 89 (9): 873–880. doi:10.1093/ptj/89.9.873.

Mullen, B., P. Muellerleile, and B. Bryant. 2001. "Cumulative Meta-Analysis: A Consideration of Indicators of Sufficiency and Stability." *Personality & Social Psychology Bulletin* 27 (11): 1450–1462. doi:10.1177/01461672012711006.

Omniewski, R. A. 1999. "*The Effects of An Arts Infusion Approach on The Mathematics Achievement of Second-Grade Students*." Unpublished dissertation, Kent State University, US.

Raja, V., and D. O. Bhalla. 2021. "Impact of Carnatic Music Training on the Mathematical Ability of Children." *Early Child Development & Care* 191 (12): 1911–1921. doi:10.1080/03004430.2020.1832484.

Ribeiro, F. S., and F. H. Santos. 2017. "Enhancement of Numeric Cognition in Children with Low Achievement in Mathematic After a Non-Instrumental Musical Training." *Research in Developmental Disabilities* 62: 26–39. doi:10.1016/j.ridd.2016.11.008.

Ribeiro, F. S., and F. H. Santos. 2020. "Persistent Effects of Musical Training on Mathematical Skills of Children with Developmental Dyscalculia." *Frontiers in Psychology* 10: 1–15. doi:10.3389/fpsyg.2019.02888.

Román-Caballero, R., M. A. Vadillo, L. J. Trainor, and J. Lupiánez. 2022. "Please Don't Stop the Music: A Meta-Analysis of the Cognitive and Academic Benefits of Instrumental Musical Training in Childhood and Adolescence." *Educational Research Review* 35: 1–22. doi:10.1016/j.edurev.2022.100436.

Sala, G., and F. Gobet. 2017. "Does Far Transfer Exist? Negative Evidence from Chess, Music, and Working Memory Training." *Current Directions in Psychological Science* 26 (6): 515–520. doi:10.1177/0963721417712760.

Sala, G., and F. Gobet. 2020. "Cognitive and Academic Benefits of Music Training with Children: A Multilevel Meta-Analysis." *Memory & Cognition* 48 (8): 1429–1441. doi:10.3758/s13421-020-01060-2.

Uttal, D. H., N. G. Meadow, E. Tipton, L. L. Hand, A. R. Alden, C. Warren, and N. S. Newcombe. 2013. "The Malleability of Spatial Skills: A Meta-Analysis of Training Studies." *Psychological Bulletin* 139 (2): 352–401. doi:10.1037/a0028446.

Vaughn, K. 2000. "Music and Mathematics: Modest Support for the Oft-Claimed Relationship." *The Journal of Aesthetic Education* 34 (3/4): 149–166. doi:10.2307/3333641.

Xie, F., L. Zhang, X. Chen, and Z. Xin. 2020. "Is Spatial Ability Related to Mathematical Ability: A Meta-Analysis." *Educational Psychology Review* 32 (1): 113–155. doi:10.1007/s10648-019-09496-y.

Yesilkaya, O. C., I. Jelen, and B. Eskioglu. 2021. "Music and Mathematics: The Effect of Matching Musical Meters with Geometric Shapes on 6th Graders' Learning Outcomes." *Education Quarterly Reviews* 4 (2): 264–279. doi:10.31014/aior.1993.04.02.245.

Zhang, Y., and Y. Zhu. 2022. "Effects of Educational Robotics on the Creativity and Problem-Solving Skills of K-12 Students: A Meta-Analysis." *Educational Studies* 1–19. doi:10.1080/03055698.2022.2107873.