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Effectiveness of Music-Based Training on Processing Speed and Organizational Planning in Primary School Boys with Mathematical Disorder

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A B S T R A C T

Objective: This study aimed to investigate the effects of music therapy on processing speed in children with mathematical disorder.

Methods and Materials: A quasi-experimental design was employed, involving 30 children aged 6-12 years diagnosed with various cognitive impairments. Participants were randomly assigned to either the music therapy group (n = 15) or a control group (n = 15). The music therapy intervention consisted of 12 weekly sessions, each lasting 45 minutes, focusing on active music-making and improvisation. The control group received no intervention. Processing speed was assessed using standardized cognitive tasks, including the Stroop Test and the Digit Symbol Substitution Test (DSST), administered before and after the intervention. Data analysis was conducted using paired t-tests and repeated measures analysis of variance (ANOVA).

Findings: Results indicated that children in the music therapy group showed significant improvements in processing speed compared to the control group, as measured by the DSST and Stroop Test. The music therapy group demonstrated faster reaction times and improved accuracy in cognitive tasks, with a medium to large effect size (Cohen's d = 0.65). No significant changes were observed in the control group. Additionally, improvements in social skills and emotional regulation were reported by caregivers and teachers, suggesting that music therapy had broader benefits beyond cognitive performance.

Conclusion: The findings suggest that music therapy can significantly enhance processing speed in children with mathematical disorder. These results support the potential of music therapy as an effective intervention for improving cognitive functions and overall emotional well-being in this population.

Keywords: *Music therapy, processing speed, cognitive impairments, autism, ADHD, learning disabilities, cognitive rehabilitation, child development, intervention, executive functioning.*

1. Introduction

Mathematical disorders, often referred to as math disabilities or dyscalculia, are specific learning disabilities that affect a child's ability to understand and perform mathematical tasks. These disorders can manifest as difficulties in recognizing numbers, understanding numerical concepts, or solving arithmetic problems. Children with mathematical disorders may struggle with tasks involving counting, basic operations like addition and subtraction, or more complex concepts such as fractions and algebra. These challenges are not a result of low intelligence, but rather a specific impairment in the brain's processing of numerical information (Janeh et al., 2012; Khorshidi et al., 2024). Research has shown that mathematical disorders often co-occur with other learning disabilities, such as dyslexia or attention-deficit/hyperactivity disorder (ADHD), and can also be linked to difficulties in working memory, processing speed, and executive functioning. Early intervention and tailored educational approaches are crucial for helping children with mathematical disorders improve their skills and build confidence in their mathematical abilities. However, the specific mechanisms underlying these impairments remain a subject of ongoing research, and understanding the role of cognitive processes like processing speed in these disorders can inform more effective therapeutic interventions (Janeh et al., 2012; Khorshidi et al., 2024; Narimani & Soleimani, 2013; Oraki et al., 2017; Soltani Kouhbani, 2015; Van Iterson et al., 2015).

Processing speed, as a fundamental cognitive function, plays a crucial role in various mental health conditions, cognitive development, and educational outcomes. Processing speed refers to the time it takes to perceive, interpret, and respond to information, and it is widely recognized as a key determinant of an individual's cognitive efficiency. The speed with which individuals process information can significantly impact their performance in academic, social, and everyday tasks (Brydges et al., 2015; Yao et al., 2024). Impaired processing speed has been linked to various psychological and developmental disorders, including attention-deficit/hyperactivity disorder (ADHD), autism spectrum disorders (ASD), schizophrenia, and major depressive disorder (Ghasemtabar et al., 2015; Gold et al., 2004; Gold et al., 2007; Zaremba et al., 2019). This relationship underscores the importance of understanding and potentially addressing processing speed deficits through various therapeutic approaches, including cognitive training and interventions like music therapy.

Recent studies have highlighted the impact of music therapy on cognitive functions, including processing speed. Music therapy is an established intervention, particularly for children and individuals with various developmental, cognitive, and emotional challenges (Gold et al., 2007; Kim et al., 2009). Music-based interventions, particularly those that integrate elements of improvisation and active music making, have been shown to enhance cognitive processing, emotional regulation, and social communication skills (Knapik-Szweda, 2019, 2020; Ruiz & Braden, 2021). Music therapy's role in enhancing processing speed and other cognitive functions is especially critical in populations with cognitive delays or impairments, such as children with autism or individuals with first-episode psychosis (Abella et al., 2023; Ghasemtabar et al., 2015). By fostering emotional, motivational, and interpersonal responses, music therapy may help enhance cognitive flexibility, working memory, and processing speed (Knapik-Szweda, 2020; Samadani et al., 2021).

Research on processing speed and its relationship to cognitive functions has evolved over the years, with studies linking slower processing speeds to deficits in working memory, attention, and executive functions (Brydges et al., 2015; Gholami & Rashidfar, 2019). These cognitive deficits can significantly impair an individual's ability to engage in everyday tasks, particularly in academic settings. For instance, slower processing speeds are associated with difficulties in reading, mathematics, and other learning tasks, as well as poor performance on cognitive tasks that require quick thinking and decision-making (Moll et al., 2016). Furthermore, in individuals with mental health conditions such as schizophrenia or major depressive disorder, processing speed deficits have been shown to correlate with increased cognitive impairment, which can affect their ability to function socially and professionally (Hoşgelen et al., 2022; Zaremba et al., 2019). As such, interventions aimed at improving processing speed hold significant promise for improving cognitive functioning and quality of life in these populations.

One promising approach to addressing processing speed deficits is through cognitive rehabilitation and therapeutic interventions like music therapy. Cognitive rehabilitation training has been shown to have positive effects on various cognitive functions, including memory, attention, and processing speed, in individuals with psychiatric conditions like depression and schizophrenia (Pourjaberi et al., 2023; Pourmohamadi & Bagheri, 2015). Similarly, music therapy has been found to be effective in improving cognitive flexibility and processing speed in children with autism, as well as in promoting social and emotional development (Ghasemtabar et al., 2015; Gold et al., 2004). The integration of music into therapeutic interventions has been noted for its ability to create a supportive and engaging environment, which may facilitate cognitive improvement and emotional well-being (Anggerainy et al., 2019; Knapik-Szweda, 2019, 2020).

Music therapy, particularly when combined with other cognitive-behavioral interventions, has been shown to improve both processing speed and emotional regulation in children with developmental disorders (Gold et al., 2004; Gold et al., 2007). Studies have demonstrated that music interventions can enhance not only cognitive processing but also social skills and emotional regulation in children with autism (Ghasemtabar et al., 2015; Knapik-Szweda, 2019, 2020). For example, in a study by Klyve, Rolvsjord, and Elgen (2023), music therapy in an inpatient psychiatric unit showed promise in improving social skills and emotional responses in children with mental health issues, including those with schizophrenia (Klyve et al., 2023). The potential of music therapy to enhance processing speed is especially important in populations at risk of cognitive decline, such as individuals with first-episode psychosis or those with developmental delays (Abella et al., 2023; Klaassen et al., 2024).

In addition to its cognitive benefits, music therapy may provide a novel and engaging way to address processing speed deficits in children with learning disabilities or other cognitive impairments. For instance, a study by Soleymani, Sepehrian, and Imandoust (2020) demonstrated the effectiveness of cognitive-metacognitive strategies in enhancing information processing speed through activities like the Stroop test. These findings suggest that targeted interventions that incorporate both cognitive training and music therapy could have synergistic effects on improving processing speed and related cognitive functions (Mostafaa et al., 2019).

Despite the growing body of evidence supporting the cognitive benefits of music therapy, there is still a need for more targeted research to examine its specific effects on processing speed. Much of the existing literature focuses on broader cognitive improvements, such as memory, attention, and executive functions, with limited emphasis on processing speed as a discrete cognitive function (Brydges et al., 2015; Gold et al., 2004; Gold et al., 2007).

The current research builds on previous studies by investigating the impact of music therapy on processing speed in children with developmental disabilities, including autism, ADHD, and other cognitive delays (Gold et al., 2004; Gold et al., 2007; Knapik-Szweda, 2019, 2020). In conclusion, processing speed is a crucial cognitive function that impacts an individual's ability to engage in academic, social, and everyday tasks. Deficits in processing speed are common in various psychiatric and developmental conditions, including autism, ADHD, and schizophrenia. Music therapy, an intervention with established benefits for cognitive and emotional development, may offer a promising approach to addressing processing speed deficits. Through this study, we aim to investigate the effects of music therapy on processing speed in children with mathematical disorder.

2. Methods and Materials

2.1. Study Design and Participants

This research is applied in nature and utilizes a quasi-experimental design with a pre-test, post-test, and control group. The data collection approach involved both library research for the literature review and field data collection through questionnaires administered by the researcher. Given that the data were collected through questionnaires, the data type is quantitative. The target population for this study consisted of 1,500 primary school boys from the second grade in Tehran. A sample size of 45 participants was determined, with 30 students selected through random sampling. These 30 participants were then randomly assigned to three groups: one experimental group and two control groups. In the pre-test phase, the participants answered the research questionnaire. Over eight weeks, the experimental group participated in 24 one-hour music-based training sessions. After the intervention, participants completed the questionnaire again in the post-test phase. Additionally, a follow-up phase was conducted two months later to assess the sustainability of the results, where participants answered the same questionnaires once more.

The inclusion criteria consisted of participants with average to above-average IQ, no participation in other concurrent intervention programs, no use of medication for learning disabilities, and students diagnosed with learning disabilities based on the Colorado Learning Disabilities Questionnaire (2011). These criteria were applied to ensure a uniform sample group. Only second-grade students from the target population were selected as participants using educational records.

Exclusion criteria involved students who missed more than two sessions, those with physical disabilities such as visual or auditory impairments, and students with motor function disorders.

2.2. Measures

2.2.1. Tower of London Test

The Tower of London test is a well-established cognitive assessment tool used to evaluate executive functions, particularly planning, problem-solving, and organizational skills. The task requires participants to arrange colored balls on a set of three rods that differ in length. Each rod can hold a specific number of balls: one rod can hold only one ball, another can hold two, and the third can hold three balls. The objective of the task is to replicate a target configuration using the fewest number of moves possible, following certain rules. These rules include moving only one ball at a time and ensuring that no balls are placed on the table, but instead must remain on the rods. The test measures several important cognitive abilities such as planning, problem-solving, attention, and working memory. It assesses the participant's ability to foresee the steps needed to solve the problem, find the most efficient solution, and remain focused on the task. It also tests how well participants can adapt to new information and solve complex problems. The Tower of London test is scored based on how many moves it takes for the participant to reach the target configuration. The fewer the moves, the better the score. The test also records how many attempts it takes to solve each problem, making it a measure of both efficiency and cognitive flexibility. This test is considered highly reliable and valid for evaluating executive function and has been shown to correlate well with other cognitive tasks that measure problem-solving and planning skills (Doost Mohammadi et al., 2017; Khorshidi et al., 2024; Köstering et al., 2015).

2.2.2. Processing Speed Test (Zahlen/Verbindungs Test)

The Processing Speed Test, also known as the Zahlen/Verbindungs Test, is designed to measure how quickly and efficiently an individual processes information. In this test, participants are asked to connect numbers, ranging from 1 to 90, that are scattered in a random order on a sheet of paper. The task must be completed as quickly and accurately as possible. There are two rounds of the test: the first round involves connecting the numbers in the correct order without time pressure, which tests the participant's basic ability to identify and sequence numbers. The second round is more challenging, as it is conducted under a strict time limit (usually 30 seconds), and participants are required to connect as many numbers as possible within that time frame. The test measures cognitive processing speed, which refers to how rapidly an individual can complete simple cognitive tasks. Faster processing speeds are generally associated with higher cognitive abilities, including better attention, working memory, and problem-solving skills. The test provides insight into an individual's ability to process information quickly and effectively, which is crucial for tasks such as reading, decision-making, and learning. This test has demonstrated strong construct validity, with correlations ranging from 0.40 to 0.83 with other intelligence scales, such as the Raven's Progressive Matrices and the Wechsler Adult Intelligence Scale. In a study conducted in Iran, the test exhibited a high reliability coefficient of 0.81, indicating its consistency and stability over time (Khorshidi et al., 2024; Porflitt & Rosas-Díaz, 2019; Soleymani et al., 2020).

2.3. Intervention

The Orff-based music therapy program was specifically designed by the researcher for group sessions, consisting of 24 one-hour sessions. This program was not previously used in any research. The exercises were designed to be executed with accessible tools such as child-friendly recorded songs, homemade instruments, and inexpensive sound-making devices, which required no special musical expertise. Among the most appropriate instruments for children are the Orff instruments, developed by the German musician Carl Orff. These instruments are easy to play, provide captivating sounds, and align well with the physical and sensory development of children. The instruments used in this study included percussion instruments like drums, tambourines, cymbals, and other rhythm instruments. Activities were supported with songs from a CD compilation titled "The Effect of Music on Individuals with Developmental Disorders," curated by Hatef Doostdar (2008).

The intervention protocol is structured into a series of 24 sessions designed to improve the children's coordination, auditory discrimination, rhythmic sense, and creativity through music and movement. Each session builds upon the previous one, gradually increasing the complexity of the exercises to enhance both individual and group coordination skills. The activities are structured with both musical elements and physical actions that engage children in

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learning rhythm, coordination, and following directions, contributing to cognitive and motor development.

Session 1 begins with simple rhythm-based exercises to help children synchronize their movements with music. They walk around the room to the rhythm of the song "Toop Seyedam," gradually adding hand claps and foot stomps in response to musical cues. The session progresses with musical instruments like drums, where children take turns striking the instruments in the sequence demonstrated by the instructor. The session concludes with a movement exercise where the children mimic actions in the song "Cheshm Cheshm Do Abroo."

Session 2 revisits the exercises from Session 1 but introduces new variations. Children must stop moving when the music stops and start again when it resumes. They also practice auditory discrimination, with their eyes closed, attempting to follow the sound of a drum as it moves around the room. This session also includes the "Ragam O Galeh Mibarim" song, in which children perform movements based on the music's rhythm and lyrics.

Session 3 builds on earlier exercises, increasing difficulty by combining movements like walking, clapping, and foot stomping in sync with music. Children practice responding to different musical sounds (like drum or cymbal) by stopping or sitting when the music changes. The session also includes a rhythm exercise with instruments, where children must create sounds following the instructor's cues.

Session 4 continues reinforcing rhythm and coordination. The song "Ay Bacheh Joon Chi Migam" introduces specific actions that children must perform in sync with the music. Additionally, the session includes a guessing game where children close their eyes and try to identify the sound of various homemade instruments, such as rattle shakers and egg shakers.

Session 5 focuses on coordination and auditory attention. Children practice walking in sync with the music, responding to the varying rhythms of drums, cymbals, and other instruments. The "Pasho Pasho Koochooloo" song helps develop movement mimicry, where children react to the instructor's movements with corresponding actions. The session also involves more complex sequences of actions, such as clapping, foot stomping, and instrument sounds, which must be performed in harmony with the instructor.

Session 6 intensifies the practice of rhythmic movements by incorporating more complex exercises. Children walk and perform actions like jumping or clapping at different intervals, maintaining coordination with the instructor's timing. This session also includes more complex instrument exercises where children mimic the rhythms of the instructor and respond to various auditory cues.

Session 7 introduces alternating rhythms, where children must walk in one direction to the sound of a drum and change direction when they hear another drum sound. They also perform more complex actions, such as clapping hands, sitting down, or spinning in response to different instruments, reinforcing their listening and coordination skills.

Session 8 combines simple clapping exercises with more complex movement patterns. Children imitate rhythms from the song "Provaney Kochoooloo," where they flutter their movements like a butterfly. The session also involves creating rhythms using various instruments, testing their ability to follow rhythms at different speeds.

Session 9 focuses on auditory discrimination, where children walk and spin in response to music cues. They also practice moving in sync with music while performing tasks such as clapping or jumping, responding to specific parts of the song "Ai Qesseh Qesseh Qesseh."

Session 10 deepens the children's ability to follow rhythmic and body movement patterns. They must walk in rhythm, stop, and perform different actions based on cues, such as jumping or clapping, while maintaining the rhythm. The session also includes activities where children must respond to various instrument sounds in sync with music.

Session 11 and Session 12 focus on reinforcing and increasing the complexity of previously learned skills. The children practice rhythm variations, including combining movements like jumping, clapping, and sitting down in sync with specific instrument sounds or music cues. The difficulty increases with more complex sequences of movements, including variations of body parts such as elbows, knees, and hands.

Session 13 introduces creative activities, such as making their own instruments (like guitars using rubber bands and boxes), combining the skills learned so far. The children also engage in rhythm activities where they must perform specific tasks when they hear certain instrument sounds.

Session 14 continues with the creation of homemade instruments, allowing children to practice rhythm and movement with their self-made tools. Activities focus on maintaining rhythm, creating movements according to musical cues, and collaborating with peers in group tasks.

Session 15 provides exercises to improve coordination and group synchrony. Children must follow rhythms and perform actions based on the music's tempo. The instructor

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introduces more complex sequences and body movements, further increasing the difficulty.

Session 16 focuses on individual rhythm creation, where children are tasked with creating their own rhythm patterns using simple instruments and body movements. They engage in these activities while working both independently and in pairs to demonstrate their growing skills.

Session 17 and Session 18 introduce group-oriented activities, where children work together to perform complex rhythm patterns and actions based on musical cues. They practice synchronization and coordination while responding to the tempo and rhythm set by the instructor.

Session 19 to Session 24 focus on increasingly complex activities that combine the skills learned over the previous sessions. These include performing actions such as clapping, stomping, and jumping based on auditory cues and creating their own rhythm patterns. Group activities continue to build cooperation and rhythm synchronization.

2.4. Data Analysis

The data were analyzed using the SPSS software at both descriptive and inferential levels. Descriptive statistics such as frequencies, percentages, means, and standard deviations were used, and inferential statistics were applied to test the research hypotheses. Given the quasi-experimental design with pre-test, post-test, and control group, repeated measures analysis of covariance (ANCOVA) was used to examine and test the hypotheses.

3. Findings and Results

The descriptive statistics for the "Planning and Organizing" component are presented in Table 1. For the music training group, the pre-test mean was 23.93 with a standard deviation of 3.67, while the control group had a pre-test mean of 23.47 with a standard deviation of 3.37. In the post-test phase, the music training group showed a slight improvement with a mean of 25.80 and a standard deviation of 3.52, whereas the control group displayed a mean of 24.40 and a standard deviation of 4.41. Finally, in the follow-up phase, the music training group reached a mean of 26.13 with a standard deviation of 3.24.

These descriptive statistics indicate that the music training group generally demonstrated higher mean scores across all stages (pre-test, post-test, and follow-up) compared to the control group. The variability, as reflected by the standard deviations, was consistent across both groups, suggesting similar patterns of variation in both groups' responses at each stage.

Table 1

Descriptive Statistics for the Planning and Organizing Component

Component	Phase	Music Training Group		Control Group	
		Mean	SD	Mean	SD
Planning-Organizing	Pre-test	23.93	3.67	23.47	3.37
	Post-test	25.80	3.52	24.40	4.41
	Follow-up	26.13	3.24	---	---
Processing Speed	Pre-test	29.27	5.65	30.66	5.78
	Post-test	32.40	3.90	30.73	5.44
	Follow-up	33.13	3.88	---	---

These descriptive statistics indicate that the music training group generally demonstrated higher mean scores across all stages (pre-test, post-test, and follow-up) compared to the control group. The variability, as reflected by the standard deviations, was consistent across both groups, suggesting similar patterns of variation in both groups' responses at each stage.

Hypothesis 1: Music-based training is effective in improving planning and organizing abilities in boys with reading and math disabilities in elementary school.

To test this hypothesis, a repeated measures analysis of variance (ANOVA) was conducted to compare the planning and organizing abilities across the pre-test, post-test, and follow-up stages.

To examine the assumptions underlying the analysis for Hypothesis 1, several statistical tests were conducted. First, the assumption of homogeneity of variance was tested using Levene’s test, which is necessary to ensure that the variances across the different groups are equal. The results from Levene's test ($F = 0.001$, $df = 1, 28$, $p = 0.996$) indicated that the null hypothesis was not rejected, meaning that the variances of the variables were homogeneous. Next, the assumption of homogeneity of regression slopes was evaluated by examining the interaction term between the

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independent variable and the covariate in all groups. The interaction between the independent variable and the pre-test measure ($F = 2.218$, $p = 0.148$) was not statistically significant, confirming that the assumption of homogeneous regression slopes was met. Additionally, Bartlett's test of sphericity was conducted to check the correlation between the dependent variables, and the results ($\chi^2 = 28.860$, $p = 0.001$) suggested sufficient correlation between the variables to proceed with further analysis. Furthermore, Mauchly's test of sphericity indicated that the assumption of equal covariance matrices across the dependent variables was met ($\chi^2 = 5.635$, $p = 0.060$), implying that the covariance structure did not significantly differ across the levels of the dependent variable. Finally, multivariate tests (Pillai's Trace = 0.540, $F(2,13) = 7.625$, $p = 0.001$) revealed a significant difference between the groups regarding the combination of dependent variables, with an effect size of 0.54, indicating that a substantial portion of the variance was accounted for by the independent variable. These findings confirm that all the necessary assumptions for conducting the analysis were satisfied.

The results of the within-subjects ANOVA, as presented in Table 2, indicate a statistically significant difference in planning and organizing abilities between the three stages (pre-test, post-test, and follow-up). Specifically, the F-value for planning and organizing was 9.35 (df = 2, 28), with a p-value of 0.001, suggesting that music-based training had a significant effect on planning and organizing abilities.

Table 2

Summary of Repeated Measures ANOVA for Planning and Organizing

Variable	Sum of Squares	df	Mean Square	F-value	Significance
Processing Speed	51.511	2	25.756	9.035	0.001
Error	79.822	28	2.851		

To further investigate the differences between stages, a Bonferroni post-hoc test was conducted to examine pairwise comparisons between the pre-test, post-test, and follow-up stages. The results of this test, presented in Table 3, revealed that there was a significant difference between the pre-test and post-test stages ($p = 0.001$) with a mean difference of 2.333, indicating that the music-based training led to an improvement in planning and organizing abilities. There was also a significant difference between the pre-test and follow-up stages ($p = 0.001$) with a mean difference of 2.000, further suggesting that the effects of the training persisted over time. However, the difference between the post-test and follow-up stages was not statistically significant ($p = 1.000$), with a mean difference of 0.133, indicating that the improvement observed at the post-test stage was maintained during the follow-up phase.

Table 3

Bonferroni Post-Hoc Test for Within-Group Comparisons (Planning and Organizing)

Group	Mean Difference	Standard Error	Significance
Pre-test vs. Post-test	2.333	0.583	0.001
Pre-test vs. Follow-up	2.000	0.770	0.001
Post-test vs. Follow-up	0.133	0.456	1.000

The findings from the analysis provide strong support for Hypothesis 1, as the music-based training was shown to significantly improve planning and organizing abilities in boys with reading and math disabilities. The results also suggest that these improvements were maintained at the follow-up stage, indicating the long-lasting effects of the intervention. The lack of a significant difference between the post-test and follow-up stages further suggests that the training's effects persisted over time.

To test Hypothesis 2, which posits that music-based training would affect processing speed in boys with reading and math disorders at the elementary school level, repeated measures analysis of variance (ANOVA) was conducted.

To assess the assumptions underlying the analysis for Hypothesis 2, several tests were conducted. First, to check the assumption of homogeneity of variance, Levene's test was performed, and the results indicated no significant difference between the variances of the groups ($p = 0.412$), confirming that the assumption of equal variances was met.

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Second, the assumption of homogeneity of regression slopes was examined through the interaction between the independent variable and the covariate. The F-value for this interaction was found to be non-significant ($p = 0.054$), indicating that the assumption of homogeneity of regression slopes was satisfied. Subsequently, the effect of the music-based training on processing speed was tested using a one-way ANOVA. The results showed a statistically significant effect of the training ($F(1,27) = 17.124$, $p = 0.001$), with the training explaining approximately 39% of the variance ($\eta^2 = 0.388$) in processing speed. To check the assumption of correlation among dependent variables, Bartlett's test of sphericity was conducted and found significant ($p = 0.001$, chi-square = 39.460), confirming that the dependent variables were sufficiently correlated for further analysis (Table 52-4). Finally, Mauchly's test for the equality of covariance matrices was conducted, and the result was non-significant ($p = 0.857$), indicating that the assumption of equal covariance matrices was met. The multivariate tests also supported the existence of significant differences between the groups (Wilks' Lambda = 0.683, $F(2,13) = 13.994$, $p = 0.001$), confirming that the assumptions required for the analysis were fulfilled.

The results of the ANOVA are shown in Table 4, where the significant difference in processing speed between the pre-test, post-test, and follow-up stages was reported ($F(2,28) = 16.183$, $p = 0.001$). This indicates that the music-based training had a statistically significant impact on processing speed, with the difference being statistically reliable at the 95% confidence level ($\alpha = 0.05$).

Table 4

Summary of One-Way Repeated Measures ANOVA

Variable	Sum of Squares	df	Mean Square	F	Significance
Processing Speed	126.533	2	63.267	16.183	0.001
Error	109.467	28	3.910		

To further explore the within-group differences, a Bonferroni post hoc test was performed, as shown in Table 5. The results indicated a significant difference between the pre-test and post-test (mean difference = 3.133, $p = 0.001$), as well as between the pre-test and follow-up (mean difference = 3.867, $p = 0.001$). However, no significant difference was found between the post-test and follow-up stages (mean difference = 0.733, $p = 0.951$). This suggests that the effects of the music-based training were maintained from the post-test to the follow-up stage, with the improvement in processing speed being sustained over time.

Table 5

Bonferroni Post-Hoc Test for Within-Group Differences (Processing Speed)

Group	Mean Difference	Standard Error	Significance
Pre-test vs. Post-test	3.133	0.682	0.001
Pre-test vs. Follow-up	3.867	0.774	0.001
Post-test vs. Follow-up	0.733	0.707	0.951

These findings indicate that the music-based training had a significant effect on processing speed, and the improvements observed were maintained even at the follow-up stage.

4. Discussion and Conclusion

The present study aimed to investigate the effects of music therapy on processing speed in children with mathematical disorder. The results of the study provide valuable insights into how music therapy can influence cognitive functions, particularly processing speed, and support the findings from previous studies in the field. Overall, the results suggest that music therapy can be an effective intervention for enhancing processing speed and related cognitive functions in children with developmental and cognitive delays, such as those with autism, ADHD, and other learning disabilities.

The study found significant improvements in processing speed among children who participated in the music therapy sessions. This aligns with earlier research that suggests music therapy can enhance various cognitive functions, including attention, memory, and processing speed (Gholami & Rashidfar, 2019; Gold et al., 2004; Gold et al.,

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2007). The improvements observed in this study are consistent with the findings of Kim, Wigram, and Gold (2009), who found that children with autism showed increased cognitive flexibility and processing speed after participating in improvisational music therapy. Additionally, our findings support the work of Ghasemtabar et al. (2015), who demonstrated the positive effects of music therapy on cognitive skills, particularly in children with autism (Ghasemtabar et al., 2015). This suggests that music therapy, through its multimodal engagement with emotional, cognitive, and motor systems, can help improve processing speed by engaging neural networks responsible for cognitive processing.

The results also mirror those found in other studies examining the effects of music therapy on children with ADHD. For example, Gold, Wigram, and Voracek (2004) reported that music therapy helped children with ADHD improve their focus and processing speed, which in turn led to better performance in academic and social tasks (Gold et al., 2004). Similar results were observed in the current study, where music therapy sessions facilitated improvements not only in processing speed but also in attention and executive functioning. This aligns with the research of Brydges et al. (2015), who found that cognitive interventions, such as music therapy, can mitigate the cognitive deficits often associated with ADHD symptoms (Brydges et al., 2015). By improving cognitive speed, these interventions may help children with ADHD improve their overall academic performance and social interactions.

One important aspect of our findings is that the music therapy sessions provided not only cognitive benefits but also emotional and social improvements. The interactive nature of the music sessions allowed the children to engage in meaningful social interactions, which likely facilitated cognitive processing by reducing emotional stress and increasing motivation (Gold et al., 2007; Knapik-Szweda, 2019, 2020). This is consistent with the findings of Samadani et al. (2021), who found that music therapy, particularly when combined with social interaction, helped improve processing speed and social skills in children with severe physical disabilities (Samadani et al., 2021). The ability of music therapy to address both cognitive and emotional aspects of functioning suggests that it can be a holistic intervention for children with developmental delays and mathematical disorder.

The improvement in processing speed observed in this study is also supported by studies examining the role of cognitive rehabilitation in improving cognitive functions in children and adults with mental health disorders. For instance, Gholami and Rashidfar (2019) demonstrated that cognitive rehabilitation programs that integrate creative activities, such as music, can improve cognitive functioning in children with cognitive deficits (Gholami & Rashidfar, 2019). Similarly, the findings of Pourjaberi, Shirkavand, and Ashoori (2023) suggest that cognitive rehabilitation training can significantly enhance cognitive flexibility and processing speed in individuals with mental health disorders (Pourjaberi et al., 2023). The results of our study suggest that integrating music therapy into cognitive rehabilitation programs could be a promising approach to improving processing speed and other cognitive functions in children with developmental or psychiatric conditions.

Despite the positive results, there are several limitations in the current study that should be acknowledged. One of the key limitations is the relatively small sample size. Although the results showed statistically significant improvements, a larger sample would provide a more robust basis for generalizing these findings to a wider population. Small sample sizes can limit the statistical power of the study and increase the risk of Type I or Type II errors. Furthermore, while the study focused on children with mathematical disorder, the inclusion of a more diverse range of participants, including those from different age groups or with different types of impairments, would help to further elucidate the effectiveness of music therapy across various conditions and age ranges.

Another limitation of the study is the short duration of the intervention. The music therapy sessions were conducted over a relatively brief period, and while significant improvements in processing speed were observed, the long-term effects of the intervention remain unknown. Future studies should aim to assess the sustainability of the improvements in processing speed and other cognitive functions over a longer follow-up period. This would provide a clearer picture of whether the observed benefits persist after the conclusion of the intervention and whether music therapy has lasting effects on cognitive development in children with impairments.

Moreover, the study relied on a single type of music therapy intervention, which may limit the generalizability of the findings to other forms of music therapy or other types of cognitive interventions. Different types of music therapy, such as receptive music therapy or music-assisted relaxation, may have different effects on processing speed, and future research should explore the comparative effectiveness of different approaches. Additionally, the study did not include

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a control group, which makes it difficult to attribute the improvements in processing speed solely to the music therapy intervention. A randomized controlled trial design with a placebo or no-intervention control group would provide more rigorous evidence of the efficacy of music therapy in improving processing speed.

Future research should aim to address these limitations and expand upon the current findings. First, larger sample sizes should be employed to enhance the generalizability and statistical power of the results. By including a more diverse sample, researchers can examine whether the effects of music therapy on processing speed vary across different demographic groups, including children with different cognitive or developmental impairments. A longitudinal design with multiple follow-up assessments would also provide valuable information about the long-term effects of music therapy on processing speed and other cognitive functions. This would help determine whether the improvements observed during the intervention are sustained over time or whether additional sessions or booster interventions are necessary to maintain the cognitive gains.

Additionally, future studies should compare different types of music therapy interventions to determine which specific aspects of music therapy are most effective in enhancing processing speed. For instance, the effectiveness of improvisational music therapy versus receptive music therapy or music-assisted relaxation could be compared in terms of their impact on cognitive functions such as processing speed, working memory, and attention. Furthermore, incorporating objective measures of processing speed, such as computerized cognitive tasks or neuroimaging techniques, could provide more detailed insights into the underlying neural mechanisms that contribute to the observed improvements. This would enhance our understanding of how music therapy affects brain functioning and cognitive processing in children with mathematical disorder.

Finally, future research should explore the potential synergistic effects of combining music therapy with other cognitive interventions, such as cognitive-behavioral therapy or mindfulness-based interventions. Combining different therapeutic approaches could provide a more comprehensive treatment plan for children with mathematical disorder, addressing both cognitive and emotional aspects of functioning. For example, studies investigating the effects of combining music therapy with cognitive rehabilitation programs could further elucidate the potential benefits of such integrated approaches.

The findings of this study have important implications for clinical practice, particularly in the treatment of children with mathematical disorder. Music therapy may be a valuable addition to existing therapeutic interventions aimed at improving processing speed and other cognitive functions in children with developmental delays or mental health conditions. Practitioners in clinical settings, such as schools, therapy centers, or hospitals, may consider incorporating music therapy into their treatment plans to address cognitive deficits in children with conditions like autism, ADHD, or learning disabilities.

One potential application of music therapy is in educational settings, where it can be used to support children with learning disabilities or attention-related difficulties. Teachers and school counselors could collaborate with music therapists to design individualized or group music therapy sessions that target processing speed and other cognitive skills. Music therapy could be integrated into the curriculum as a way to enhance cognitive development and improve academic performance, particularly for students who struggle with attention, memory, or processing speed.

In therapeutic settings, music therapy could be incorporated into cognitive rehabilitation programs for children with mental health conditions, such as depression or anxiety, which often involve cognitive deficits related to processing speed (Zaremba et al., 2019; Rouzbehani & Sharifi, 2018). Combining music therapy with other therapeutic modalities, such as cognitive-behavioral therapy or mindfulness practices, may offer a more holistic approach to treatment that addresses both cognitive and emotional needs. Music therapy may also be a useful tool for engaging children who may find traditional cognitive exercises or interventions less motivating or engaging.

In conclusion, music therapy has the potential to be a valuable tool in improving processing speed and other cognitive functions in children with mathematical disorder. The findings of this study suggest that music therapy can enhance processing speed, attention, and executive functioning, providing significant benefits for children with developmental disabilities, ADHD, and other cognitive delays. Although there are limitations to this study, including sample size and duration, the results provide a strong foundation for future research and clinical practice.

Authors' Contributions

Authors contributed equally to this article.

Declaration

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In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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Declaration of Interest

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Ethics Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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