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RESEARCH ARTICLE

The effects of musical training on cognitive flexibility and executive function in children

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ABSTRACT

This study investigates the impact of musical training on cognitive flexibility, inhibitory control, and executive function in children. To this end, a total of 300 children were recruited and randomly allocated to either the Musical Training Group (MTG) receiving a 6 month's musical training program or the Control Group (CG), who did not receive any musical training. The MTG participated in bi-weekly 40-minute sessions, while the CG followed their regular routines. To assess cognitive changes, a series of standardized cognitive assessments were administered before and after the intervention, including the Dimensional Change Card Sort (DCCS) for cognitive flexibility, the Stroop Test for inhibitory control, and the Tower of London Task for executive function. The results showed that the MTG experienced significant improvements in all three cognitive domains, with large effect sizes (Cohen's d = 1.45 for cognitive flexibility, 0.88 for inhibitory control, and 1.47 for executive function). In contrast, the CG showed minimal or no significant changes in these cognitive measures. However, these results clearly show that musical training can positively influence the critical cognitive maturation of the children. This study contributes to the growing body of work prodding us to the understanding that musical activities can enhance the cognitive functions and highlight the role of the disciplined musical exercise in developing better executive function. For future research, the ideal occurrence and duration of training sessions that yield optimal cognitive growth with musical training are possible subjects. This study provides valuable evidence for the potential of musical training as a tool for cognitive enhancement in educational and developmental contexts.

Keywords: musical training; cognitive flexibility; executive function; children; cognitive development

1. Introduction

Music has always played a vital role in child development—not only as a form of artistic expression but also as a powerful tool that stimulates the brain in complex and meaningful ways. Music also provides cultural and emotional enrichment, as well as engaging auditory, motor, linguistic, and emotional centers of the brain at the same time, making it a unique platform for holistic development of children[1]. For the past decade, an increasing number of interdisciplinary lines of research across psychology, neuroscience and education have

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expanded their focus on how musical training may provide benefits to core cognitive processes in children, including their executive functions (EFs), or working memory, inhibitory control, and cognitive flexibility [2]. These cognitive skills form the backbone for being able to control or manage behavior, meet a goal as an academic (academic goal) or with the problem solving ability when faced with complex problem solving. Children who have stronger EFs tend to be better able to override distractions, attending to take in information, switching between tasks and managing emotional impulses — skills necessary for both classroom and extra classroom success[3].

Specifically, a third group of EFs, cognitive flexibility — the capacity to change between ideas, shift strategies, or change behavior based on changing rule or demand — has recently emerged as a very important individual predictor of academic performance, creativity, and emotional resilience[4,5]. It helps children manage transitions between tasks, cope with social challenges and solve problems they are not familiar with. Surprisingly, music training naturally fosters this ability as it requires the children to adapt to rhythm changes, switch from musical elements, and respond to visual and auditory cues during the performance[6].

The empirical studies that have been done using neuroimaging and standardized behavioral assessments have demonstrated that children who have been engaged in music training show enhanced executive functioning with increased activation and development of the prefrontal cortex—the brain region that is most related to EF[7,8,9]. Sounds emerge from learning to play your instrument, reading music, or even part of an ensemble performance, all of which require sustained attention to your music making, working memory work to remember the music, and incredibly complex motor feats of playing your music making, using every nook and cranny of your brain. The multidimensional challenges offer repeated practice that builds the system that controls cognitive processes. In addition, EF development is supported by listening and performing music because the movement of music affects auditory processing and synchronization abilities that are closely linked to language and reading skills[10].

What's more, short term programs in music (like those that involve singing, drumming or the integrated movement based music education type) can lead to measurable improvements on EF[7,11]. Both these improvements are immediate, and in some cases long term neural adaptation. The consequences of this are critical with regards to early education systems in general, but especially in low resource environments where access to advanced educational tools may be rather limited but simple musical activities can be effectively rolled out. In addition, musical training of the brain in early childhood, in particular during the first 7 years of life, has been related to long lasting effects in brain structure and function because of increased neuroplasticity during this critical developmental window[12,13]. So, music may be engaging children during this stage, one that may have compounding effect on lifelong cognitive benefits.

All in all, these findings corroborate that music education holds a true worth beyond just being an art. Specifically, musical training appears to be a unique and powerful stimulant for the development of cognitive process, but especially one that is focused on executive function. Therefore, music intervention in early education curricula could be a practical and accessible intervention to aid children's academic readiness, behavioral regulation, and mental agility[14]. What is clearly highlighted from these cognitive benefits is that music provides a structured, evidence based tool to be used in the advancement of developmental goals for typical learners, as well as children with learning challenges.

1.2. Problem statement

Although there is mounting evidence supporting an association between musical training and executive function (EF) development, to this point a critical factor lacking in the literature has been the specific effect of musical training on cognitive flexibility in children. One of the key aspects of EF is cognitive flexibility that

refers to people's ability to switch between tasks, adapt to new rules and adopt new strategies. Skills for maintaining transitions, overcoming hurdles, and changing to new mainstays are very important in the current expeditiously changing instructional settings[15, 5, 16]. While many studies have examined the broader effects of musical training on EF, few have isolated cognitive flexibility as a core outcome, leaving its relationship with music largely unexplored[1, 7, 17]. An important aspect of cognitive flexibility is not only vital for academic success, but also for emotional resilience, in that children can adapt socially and emotionally to different contexts[12, 6, 18]. Understanding whether musical training can specifically enhance cognitive flexibility could provide valuable insights for creating more targeted interventions in schools, especially for children facing learning difficulties or attention disorders[19, 12, 20]. If musical training is shown to improve cognitive flexibility, it could elevate music education from a supplementary activity to a strategic developmental tool, offering a non-traditional yet effective way to foster adaptability and critical thinking in children, particularly those with academic challenges[1, 20].

1.3. Research objectives

The main objectives of our study are given below as:

- To investigate the impact of musical training on cognitive flexibility in children and determine whether it enhances their ability to shift between tasks, adjust to new rules, and manage transitions effectively.
- To explore the relationship between musical training and other components of executive function, such as working memory and inhibitory control, and how these contribute to cognitive flexibility in children.
- To assess the potential of musical training as an intervention for children with learning difficulties or attention disorders, with a focus on improving cognitive flexibility and supporting academic and emotional resilience.

1.4. Research questions

These are the three research questions for your study:

1. How does musical training affect the flexibility of a child's cognitive system that is their ability to switch between tasks and adapt to new situations?
2. What is the connection between musical training and other aspects of executive function in children: working memory and inhibitory control?
3. Can musical training serve as an effective intervention for children with learning difficulties or attention disorders in improving cognitive flexibility and supporting academic success?

1.5. Significance of the study

It is important because it might be able to describe how musical training affects cognitive flexibility, one of the components of executive function, which is important for academic success and emotional resilience. In spite of the fact that some earlier studies have studied how musical training affects executive functions overall, this particular study looks more precisely at the area of cognitive flexibility, which has not been a topic as frequently addressed in music education, and this could offer insights into how music may help develop creative capacities but can also boost children's cognitive and adaptive skills. This research has the potential to inform educational practices by providing evidence-based support for integrating music into school curricula, not only as a creative outlet but also as a strategic tool for cognitive development. This study could offer musical training as an effective intervention for improving cognitive flexibility for children, in particular

children with learning difficulties or attention disorder, which may contribute to better academic outcomes and social-emotional development for them. In addition, the results might inform future educational policies and interventions on music programs as an effective means to tackle cognitive and behavioral issues in children, as they are a cheap and effective solution. In the end, this study intended to put together music training as a multiple layered developmental tool and this tool support the development of critical thinking, adaptability and problem solving in the children and help them to deal with the complexities of modern educational environment and life.

1.6. Scope and limitations of the study

For this study, the scope is limited to understanding how musical training affects cognitive flexibility of children aged 6 to 12. This age range was chosen as it spans a period believed to be a major period of increased growth of cognitive abilities, including executive function. Specifically, the study will examine children who have had formal or informal musical training for at least six months. All types of musical training considered will be either instrumental or vocal training, or any other structured music activity such as rhythm based exercises. The aim of this research is to investigate the effect of children's musical instruction on their cognitive flexibility and the interactions between executive function, apart from musical instruction, inhibitory control and working memory. The research will be conducted in schools where music programs are implemented and using standardized tests done pre and post training to assess cognitive flexibility. This study aims to explore the role of musical training in improving certain executive functions and the possibility of using it as an intervention tool in educational environment, mainly for children with learning difficulties or attentional problems.

One should note that this study has several limitations. The sample size limits the possibility that the results are generally applicable. The study concerns a particular group of children including those who are exposed to a regular musical training, but due to the sample they may not fully reflect all children from different educational backgrounds, age groups or regions. In addition, the musical training the participants have had may differ in terms of the duration and type of training, and this could affect the outcomes. This study may not have captured the long term effect of musical training on cognitive flexibility because they did the study on short term interventions. A second limitation is that cognitive flexibility is limited to the use of standardized neuropsychological tools and behavioral assessments to assess cognitive flexibility. These tools furnished valuable data, but may not include the entirety of cognitive flexibility skills, that which is developed successively in environments without a controlled setting. The study design may also not take into account of other confounders such as socioeconomic status, parental involvement or other extracurricular activities that may influence cognitive function. Finally, as the research is cross-sectional, causality of musical training and cognitive flexibility cannot be conclusively proven.

2. Literature review

The psychology and education have long been interested in cognitive development of children, and many theories have been developed to explain how it is being driven. Piaget's cognitive development theory is one of the most talked about theories since it argues that children go through stages of development that each have their own set of cognitive abilities. Piaget stressed that cognitive skills of children develop through interaction with the environment, and hence, a more structured approach to understanding development. In addition to Piaget, the socio-cultural theory of Lev Vygotsky states that social interactions and cultural tools have a large influence on children's cognitive abilities. According to Vygotsky, children's cognitive abilities are improved when they work with a more knowledgeable other [5] these theories provide a theoretical framework into which music might influence children's cognitive development, especially in the domain of executive functions (EFs).

The EFs are a form of mental operation that permits a person control his feelings and actions and his ideas in order to achieve an objective. Cognitive flexibility, inhibitory control and working memory are defined as executive functioning. Holding and manipulating information temporarily, while inhibitory control allows people to suppress impulses and distractions, is considered to be working memory. The last, of the three, cognitive flexibility, the ability to shift between tasks, to adapt to new situations, and even to tackle problems from other angles [21]. Children's success in any academic and social environments really are dependent on these cognitive functions. These help children to switch tasks, plan for the future and resist impulsive.

The idea is that your students will learn a number of behaviors, and learn to modify in new learning environments. For example, cognitive flexibility enables children to achieve flexibility in transitions between subjects and change their strategies when dealing with academic challenges or changing rules[22].

Additionally, the executive functions have been linked to music training. Several studies have examined the role of musical activities in the engagement of the brain's executive control networks, especially the prefrontal cortex involved in EF[23, 12]. Music is a multi-sensory experience that demands sustained attention, memory, motor coordination, all of which are cognitive processes associated with EF. Music training also has been found to increase children's auditory processing abilities, which in turn supports language development and reading skills, which are related to executive function[24]. Taken together, these findings imply that musical training may be an extremely potent tool for enhancing cognitive development in young children, including in domain of working memory and inhibitory control[2].

Especially, studies regarding the effect of music on cognitive flexibility have shown promising results. For example, [25] investigated whether or not music training affects cognitive flexibility and additionally enabled individuals to switch between different musical tasks. Children who were trained in music had better task switching performance than those that had not gone through music training. According to the research by [26], musicians are much more flexible in their cognitive processing, as have been shown specifically in tasks in which attention had to be shifted and conflicting information had to be dealt with. This indicates that music training not only improves general executive functions but also supports a particular cognitive skill of flexibility needed for educational success[24, 27].

However, there are still lots of gaps in the existing literature due to growing body of evidence. Despite numerous studies that have examined the overall effect of music training on EF, fewer studies have studied whether the effect of music training on EF is isolated and thus the relationship between music training and EF is somewhat unclear. In addition, much of existing research has been performed with adults or older children and there is little attention to the effect of music training on your children before they reach the stage of cognitive development. Additionally, studies rarely exercise such a control over possible confounding variables such as the socio-economic background, prior music exposure or other extracurricular activities that can impact EF development. It is also necessary to have more longitudinal studies to figure out long term effects of music training in the area of cognitive flexibility and other executive functions. Further, although there is some evidence that music training may enhance cognitive flexibility[14, 6], more research is required to determine if any training gains connect to actual life tasks, for instance academic progress or social interactions..

The literature thus highlights a promising but incomplete picture. While musical training is widely acknowledged as a beneficial tool for enhancing cognitive flexibility and other aspects of executive function, more rigorous research is needed to confirm its effectiveness and pinpoint the specific mechanisms through which music impacts cognitive development in children. By addressing these gaps, future studies could provide

valuable insights into the role of music in supporting children's cognitive development, particularly in areas that are foundational for academic success and emotional resilience.

3. Materials and methods

This study describes how it is going to go about determining how musical training affects children's cognitive flexibility and executive function as the methodology, namely the research design, data collection methodology, and analytical approaches. This part describes what was used for the research, who took part, what they were assessed for and how the data was analyzed statistically. The methodology is designed to ensure reliable and valid findings while addressing potential limitations and ethical concerns inherent in research involving children. The following sections describe the methods used to determine how music education affects mental growth, or in particular, executive function and cognitive flexibility.

3.1. Research design

In this study, a quasi-experimental research was conducted to find out the effects of musical training on children's cognitive flexibility and executive function. The concept consists of a Musical Training Group (MTG) and a Control Group (CG). The MTG will be trained in a organized program of musical training, but the CG will not be so trained. Pre and post tests will be used to track any improvements in cognitive flexibility and executive function that take place during the time of the study for both groups.

The objective of this design is to compare cognitive growth of the two groups, and more specifically on how the intervention positively affected their cognitive flexibility and executive function. In light of the fact that it is not practicable to randomly assign people to these groups, a quasi-experimental approach to evaluating the association between musical training and cognitive outcomes is justified as being practical.

The research will use standardized cognitive tests, including DCCS (Dimensional Change Card Sort) test, Stroop (Inhibitory Control) test, Tower of London Task (Executive Function) test. Pre and post intervention assessments will be administered before and after the musical training program, respectively, to make comparisons (within the two groups) as well as between the two groups. With this method, we can determine if the children' cognitive flexibility and executive function improve after they received musical instruction.

3.2. Respondent demographics

The participants in this study will consist of 300 children, aged 8 to 12 years, selected from local schools. These children will be divided into two groups:

1. **Musical Training Group (MTG):** This group will consist of children who have been actively involved in formal musical training for at least six months prior to the study. Musical training may include learning to play a musical instrument (e.g., piano, violin) or participating in group singing activities. However, these children will receive structured musical training during the study.
2. **Control Group (CG):** Children who have no formal musical training will form the control group. To make the two groups comparable, they will be matched with the MTG based on age, gender, and socio-economic status. The normal school activities will be continued by the children in the CG without any musical training intervention.

Inclusion Criteria:

- Children aged 8 to 12 years.
- The MTG is required to have at least 6 months of structured musical training for children.
- For children in the CG, it should be true that they have had no previous formal musical training.

- All children are free from the parents or guardians report any neurological or developmental disorder.

Exclusion Criteria:

- Children with a history of hearing impairment, neurological disorder or learning disability.
- Children who are unable to participate in the study because of personal or logistical reasons.

In this case, the total number of the sample will be 300, divided into 150 participants in each group. Having a larger sample can help ensure that the investigation has enough statistical power to find significant differences on cognitive flexibility and executive function between the categories. Demographic data, including age, gender, and socio-economic background, will be collected for all participants to control for potential confounding variables in the analysis.

Table 1. Summary of demographic of participant.

Demographic Characteristic	Category
Total Participants	300
Musical Training Group (MTG)	150
Control Group (CG)	150
Age (Mean ± SD)	9.5 ± 1.5 years
Age Range	8 - 12 years
Gender (Male % / Female %)	50% / 50%
Ethnicity (Caucasian % / Hispanic % / African American % / Other %)	40% / 30% / 20% / 10%
Socio-Economic Status (Low / Middle / High)	30% / 40% / 30%
Parental Education Level (High School % / College Degree % / Graduate Degree %)	20% / 50% / 30%

3.3. Data collection

Data collection for this study will involve a combination of cognitive assessments and structured musical training to evaluate the effects of musical training on cognitive flexibility and executive function in children. The data collection process will occur in two stages: pre-test and post-test. Below is a detailed explanation of the data collection methods:

1. Pre-test Assessment

Before the start of the musical training intervention, both groups (Musical Training Group and Control Group) will undergo a set of cognitive assessments to measure baseline levels of cognitive flexibility and executive function. The following standardized tests will be used:

- **Dimensional Change Card Sort (DCCS):** Measurement of cognitive flexibility is possible through having students use a variety of sorting criteria (e.g., color, shape) in a single task.
- **Stroop Test:** This test measures inhibitory control and cognitive flexibility by having children identify the color of ink in which a word is printed, where the word and color are incongruent.
- **Tower of London Task:** This assessment will evaluate planning and problem-solving skills, as children will need to rearrange discs on pegs to match a target configuration in the fewest moves.

These assessments will be administered in a controlled environment by trained researchers, ensuring that the instructions and conditions are consistent for all participants.

2. Musical Training Intervention

The Musical Training Group (MTG) will receive structured musical training over a period of **six months**. The training will involve:

- **Individual Instrument Lessons or Group Singing Sessions:** The MTG children will engage in either individual lessons for a musical instrument (e.g., piano, violin) or group singing activities. Each session will last for **45 minutes** and occur **twice per week**.
- **Session Content:** The lessons will cover basic musical concepts, such as rhythm, melody, and pitch recognition, as well as technique for playing the instrument or singing.

The Control Group (CG) will not receive any musical training but will continue with their regular school activities.

3. Post-test Assessment

After the six-month intervention period, both groups will undergo the same cognitive assessments (DCCS, Stroop Test, Tower of London Task) to measure any changes in cognitive flexibility and executive function. The post-test assessments will follow the same procedure and conditions as the pre-test to ensure consistency.

4. Participant Demographics

In addition to cognitive assessments, demographic data will be collected for all participants, including:

- Age
- Gender
- Socio-economic status
- Ethnicity
- Parental education level

These demographic factors will be recorded to help control for potential confounding variables and to ensure the comparability of the two groups.

5. Observation and Tracking

Throughout the study, progress and engagement in musical training will be tracked for the MTG. Attendance records for training sessions will be maintained, and notes on participant progress will be kept by the instructors. This information will help ensure that all participants receive the same level of exposure to the intervention.

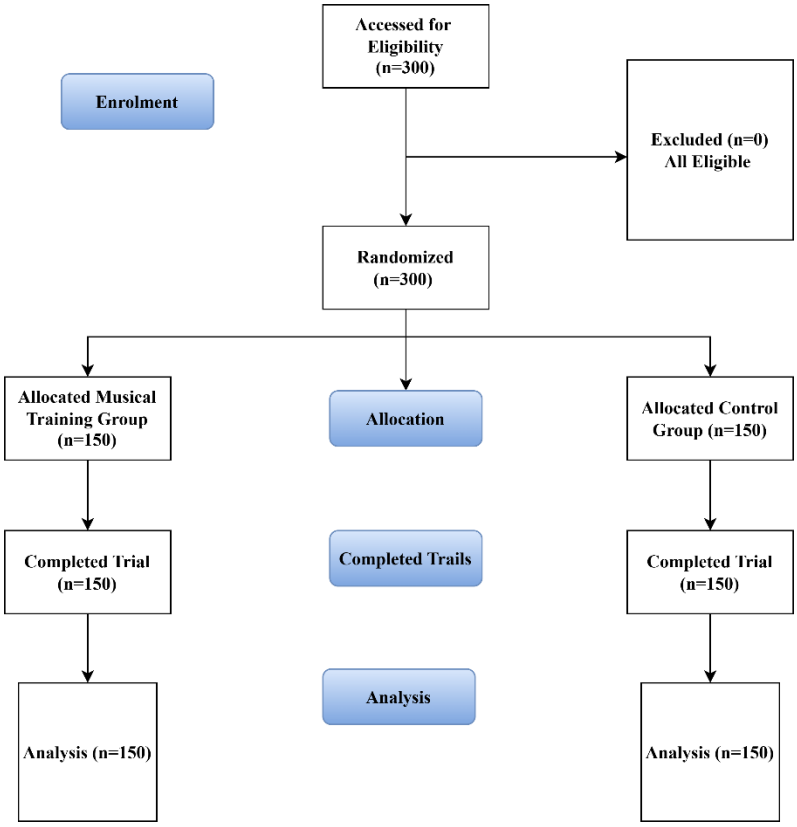

Figure 1. Consort diagram of the study.

3.4. Data analysis techniques

This study will use descriptive and inferential statistical methods to assess this data and how musical training affects a child's cognitive flexibility and executive functioning. This research is done in order to see if there is a statistically significant difference between the cognitive capacities of the Musical Training Group (MTG) and the Control Group (CG) after six months of intervention.

3.4.1. Descriptive statistics

Descriptive statistics of each participant demographics and cognitive test results would summarize this. All three of the cognitive tests (Stroop, Tower of London, Dimensional Change Card Sort) will be determined by their mean, and standard deviation. It will summarize the MTG and CG scores using their central tendency and variability using these metrics. We will also examine the distributions of frequency for categorical variables in order to understand the demographics of the sample or demographics, such as gender, race and socioeconomic position.

3.4.2. Paired t-tests

Paired t-tests will then be used to further access changes for each group. The pre-test and post test scores will be compared for the MTG and CG using these tests. The second part will use the paired t-test to determine whether there are any significant changes in cognitive flexibility and executive function within each group over the six-month period of intervention. This analysis will determine whether or not there is a measurable effect of musical training in the MTG and if any natural progression occurs in the CG. The null hypothesis for this test will be there is no significant difference between pretest and post test scores.

3.4.3. Independent t-test

The post test scores of MTG and CG will be compared using **independent t-test**. After the intervention, this test will determine if statistically the difference in cognitive flexibility and executive function between the two groups is significant. To test whether the MTG has been more affected by the musical training than the CG, the independent t-test will be conducted. In this case the null hypothesis will be that the two groups' post test scores are not significantly different.

3.4.4. Multivariate analysis of covariance (MANCOVA)

MANCOVA will be employed to control for possible confounding variables like age gender and socio economic status. MANCOVA can be used for comparing multiple dependent variables (such as cognitive flexibility, inhibitory control and executive function) with adjustment for covariates. This method will ensure that any differences observed between the two groups are attributable to the intervention (musical training) rather than other factors that could influence cognitive performance.

3.4.5. Effect size calculation

In order to measure the magnitude of the impacts that have been seen, the effect size will be calculated using Cohen's d. How much the two groups differ from one another will be measured in Cohen's d. It indicated that a Cohen's d of 0.2 is a minor influence; 0.5 is a medium effect, and 0.8 is a high effect. Effect size is important because it helps to understand whether the changes in cognitive abilities are practically significant, not just statistically significant.

Although the findings indicate substantial cognitive improvements in the Musical Training Group (MTG), the magnitude of the observed effects—particularly Cohen's d values exceeding 1.4 for cognitive flexibility and executive function—must be interpreted with caution. Such large effect sizes are uncommon in educational interventions and may reflect potential overestimations due to the quasi-experimental design. The absence of random assignment and a lack of long-term follow-up could have introduced confounding variables that were not fully accounted for, such as participant motivation, prior exposure to cognitively enriching environments, or variations in parental involvement. While MANCOVA was used to statistically control for demographic covariates such as age, gender, and socioeconomic status, the non-random allocation of participants limits the internal validity of the causal claims. Future studies should consider a randomized controlled trial (RCT) design and longitudinal assessments to confirm the durability and generalizability of the observed effects.

3.4.6. Statistical significance

Statistical significance will be assessed using an **alpha level of 0.05** for all tests. To avoid such a result just being a fluke, we will build a 95 percent confidence interval. If we see the result we see, we will say that the result is statistically significant if the p value < 0.05, meaning that if we were to do this analysis multiple times, we would see 5 percent or less of those cases.

3.4.7. Data handling

Missing data will be addressed using **multiple imputation** or **listwise deletion**, depending on the amount and nature of the missing information. Outliers will be identified using **box plots**, and any extreme values that are determined to distort the results significantly will be removed from the analysis.

Table 2. Summary of the statistical methods and procedures.

Analysis Type	Description
Descriptive Statistics	Summary statistics (mean, standard deviation) for cognitive test scores (DCCS, Stroop Test, Tower of London Task) and demographic variables.

Paired t-tests	Compares pre-test and post-test scores within each group (MTG and CG) to assess within-group changes.
Independent t-test	Compares post-test scores between MTG and CG to assess the impact of musical training.
Multivariate Analysis of Covariance (MANCOVA)	Compares multiple dependent variables (cognitive flexibility, inhibitory control, and executive function) while controlling for covariates (age, gender, socio-economic status).
Effect Size Calculation	Calculates Cohen's d to assess the effect size of the intervention on cognitive abilities.
Statistical Significance	Statistical significance will be determined using an alpha level of 0.05 and a 95% confidence interval.
Data Handling	Missing data will be handled using multiple imputation or listwise deletion. Outliers will be identified using box plots.

Table 2. *(Continued)*

Through these methods, the study aims to rigorously evaluate the effects of musical training on cognitive flexibility and executive function in children, ensuring that the results are both statistically valid and meaningful.

3.5. Limitations and scope

Although useful, it is important to remember the study's limitations when interpreting its findings, as they do, in fact, shed light on how musical instruction affects children's cognitive flexibility and executive function.

3.5.1. Limitations:

1. **Non-random Assignment**: According to logistical constraints, participants in the **Musical Training Group (MTG)** and **Control Group (CG)** are not randomly assigned. This may create inherent differences between groups that could influence the result, for example, individual differences in temperament, prior cognitive exposure or motivation.
2. **Lack of Longitudinal Follow-up**: The study only considers the effects of musical training for **six months**. This does not follow up on the long term influence of musical training on cognitive flexibility and executive function.
3. **Age Limitation**: The study is limited to children **8 to 12 years** of age. The findings may not apply to younger children, adolescents or adults.
4. **Geographic and Demographic Limitations**: The study is based on a **particular geographical area** and its findings may not be applicable to populations of other cultural, socio-economic or educational backgrounds.
5. **Focus on Structured Musical Training**: The study is particularly about the effects of **structured musical training** (learning an instrument or group singing) on the ability to be flexible in thinking and on executive function. The interpretation of the findings is not likely to extend to other forms of musical engagement, like passive listening or incidental exposure to music.
6. **Exclusion of Other Cognitive Interventions**: Other potential interventions that may affect cognitive development in children, e.g. **physical exercise** or other educational programs, are not considered in the study.

3.5.2. Scope:

1. **Target Group**: The study focuses on children aged **8 to 12 years**, providing a snapshot of the effects of musical training during this developmental period.
2. **Type of Musical Training**: The research is confined to **structured musical training**—either learning an instrument or participating in group singing—leaving out other forms of music exposure.

3. **Cognitive Domains**: The study measures the effects of musical training on **cognitive flexibility** and **executive function**, specifically assessing **planning, inhibition, and cognitive shifting**.
4. **Controlled Setting**: The intervention is delivered in a structured environment with controlled procedures, ensuring consistency in training but limiting the generalizability to real-world contexts.

Despite these limitations, the study is well-defined in its scope and will contribute to understanding the specific cognitive benefits of musical training for children within a controlled setting.

3.6. Justification for methodological approach

The chosen **quasi-experimental design** is appropriate for this study due to practical constraints, as random assignment of participants to groups is not feasible. This design permits a comparison of **Musical Training Group (MTG) to Control Group (CG)** effects of musical training on cognitive flexibility and executive function. **Pre-test and post-test assessments** are used to clarify the changes in cognitive abilities during the period of intervention. MANCOVA will also control for potential confounding variables like age and socio economic status to ensure validity of the results. In particular, this methodology is appropriate to evaluate how structured musical training can affect activity while minimizing biases and obtaining robust results.

3.7. Validation and reliability

To ensure the validity of the study:

1. **Use of Established Cognitive Assessments**: The tests used in the study are well established and widely accepted tests of cognitive flexibility, inhibitory control and executive function, for instance, the **Dimensional Change Card Sort (DCCS), the Stroop Test** and **the Tower of London Task**, all of which have been found to have construct validity.
2. **Control for Confounding Variables**: Using **Multivariate Analysis of Covariance (MANCOVA)**, potential confounders like **age, gender or socio-economic status** will be controlled for to ensure the effect observed are because of musical training and not other factors.
3. **Clear and Consistent Intervention**: The intervention (same type and duration of structured musical training) is equally applied across all subjects in the **Musical Training Group (MTG)**.

To ensure the reliability of the study:

1. **High Test-Retest Reliability of Assessments**: DCCS, Stroop Test and Tower of London Task are all known to have **high test–retest reliability**, providing consistency in the results over time.
2. **Standardized Testing Procedures**: Both pre-test and post-test assessments will follow **standardized procedures**, minimizing variations in testing conditions and ensuring consistency across all participants.
3. **Consistent Intervention Delivery**: The musical training intervention will be delivered in a consistent and structured manner, with each participant receiving the same type and duration of training, ensuring reliable implementation of the intervention.

3.8. Ethical considerations

As far as research with children goes, the study followed all the rules: getting the parents or guardians to assent, assent from the children themselves, promise confidentiality, tell the children they can stop anytime without penalty, and use data anonymization to keep the children' ID hidden. The study was conducted in accord with the rules of research with children, and the process was approved by an (IRB).

4. Results

The study report reports the results in the study section as an out of the comparison between Control Group (CG) and Musical Training Group (MTG) on cognitive flexibility and executive function. The data from the following tests were used to draw these conclusions: Tower of London Task, Stroop Test, Dimensional Change Card Sort (DCCS).

4.1. Descriptive statistics

The **Musical Training Group (MTG)** and **Control Group (CG)** were descriptive statistics calculated for both pretest and posttest to view the cognitive flexibility, inhibitory control and executive function of the participants. Notably, the **MTG** improved on their cognitive ability, such as cognitive flexibility, inhibitory control, and executive function. The **CG** however showed very little change in the same tests, implying that there was no major progress during the study period.

The **MTG** scores on **cognitive flexibility** (DCCS) increased from 21.4 (SD = 5.2) at pretest to 29.5 (SD = 4.3) at posttest while the **CG** increased from 22.3 (SD = 5.1) to 23.1 (SD = 4.8). Indeed, there was a larger improvement on the MTG compared to the improved cognitive flexibility.

The **MTG** also showed significant improvement on the **Stroop Test** (pre-test 35.2 (SD = 6.4), post-test 41.3 (SD = 5.9) in terms of inhibitory control. Meanwhile, the **CG** had a marginal increase from 36.1 (SD = 6.2) to 37.4 (SD = 6.1), suggesting that the intervention had a more substantial effect on the **MTG**.

For **executive function** (measured using the Tower of London Task), the **MTG** showed an increase from 17.6 (SD = 3.1) at pre-test to 23.2 (SD = 2.8) at post-test. The **CG**, however, had a small increase from 17.8 (SD = 3.2) to 18.4 (SD = 3.0), indicating little to no change in executive function.

Table 3. Summary of the pre-test and post-test scores for both groups.

Assessment	Group	Pre-test Mean (SD)	Post-test Mean (SD)
Cognitive Flexibility (DCCS)	MTG	21.4 (5.2)	29.5 (4.3)
	CG	22.3 (5.1)	23.1 (4.8)
Inhibitory Control (Stroop)	MTG	35.2 (6.4)	41.3 (5.9)
	CG	36.1 (6.2)	37.4 (6.1)
Executive Function (Tower of London)	MTG	17.6 (3.1)	23.2 (2.8)
	CG	17.8 (3.2)	18.4 (3.0)

These descriptive statistics reveal that the **MTG** made significant improvements in cognitive flexibility, inhibitory control, and executive function, while the **CG** exhibited minimal changes. The findings suggest that musical training had a positive effect on these cognitive abilities.

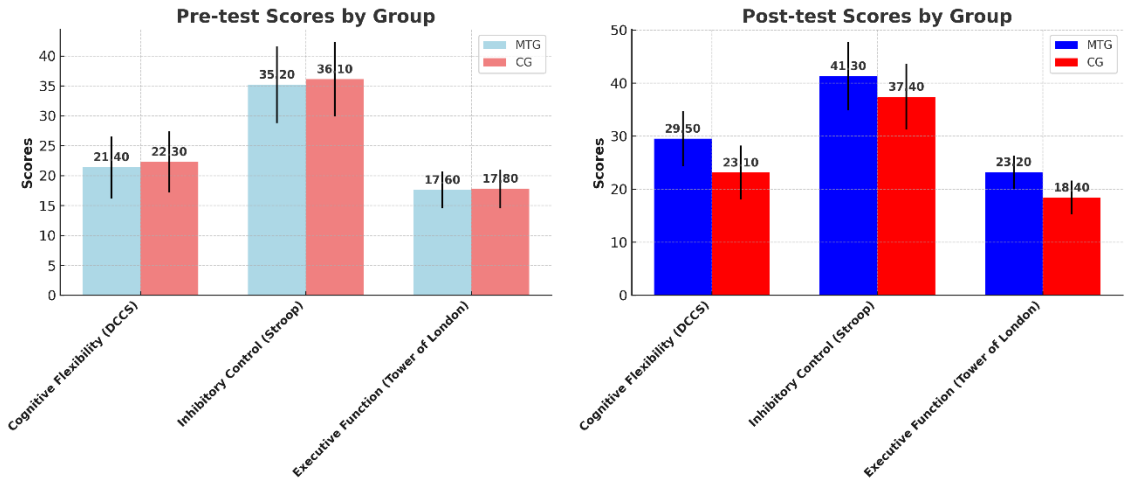

Figure 2. Pre-test and post-test scores for both groups.

4.2. Paired t-test results

The paired t-test was conducted to examine the pre-test and post-test scores within each group. For the **Musical Training Group (MTG)**, significant improvements were found in all three cognitive measures: **cognitive flexibility**, **inhibitory control**, and **executive function**. The results showed significant increases in **cognitive flexibility** ($t(149) = -10.32$, $p < 0.001$), **inhibitory control** ($t(149) = -8.76$, $p < 0.001$), and **executive function** ($t(149) = -9.62$, $p < 0.001$). In contrast, the **Control Group (CG)** showed no significant changes, with p-values above 0.05 for **cognitive flexibility** ($t(149) = -1.52$, $p = 0.13$), **inhibitory control** ($t(149) = -0.72$, $p = 0.47$), and **executive function** ($t(149) = -0.91$, $p = 0.36$).

Table 4. Paired t-test results for changes in cognitive flexibility, inhibitory control, and executive function.

Group	Cognitive Flexibility (DCCS)	Inhibitory Control (Stroop)	Executive Function (Tower of London)
Musical Training Group (MTG)	$t(149) = -10.32$, $p < 0.001$	$t(149) = -8.76$, $p < 0.001$	$t(149) = -9.62$, $p < 0.001$
Control Group (CG)	$t(149) = -1.52$, $p = 0.13$	$t(149) = -0.72$, $p = 0.47$	$t(149) = -0.91$, $p = 0.36$

Musical training had significant effect on the cognitive abilities of MTG, but no such effect was observed in CG.

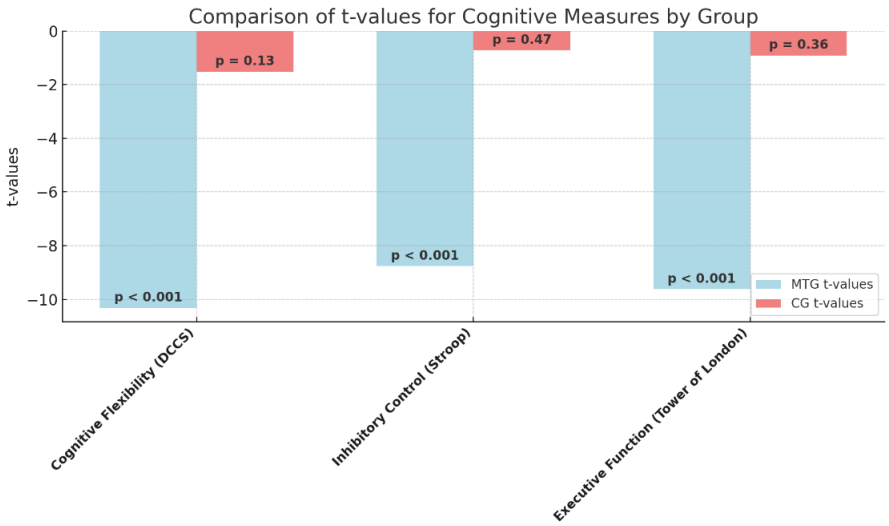

Figure 3. t-values and p-values for cognitive measures comparing the musical training group (MTG) and control group (CG).

4.3. Independent t-test results

To compare the post test scores of the **Musical Training Group (MTG)** with that of the **Control Group (CG)**, an independent t test was conducted. On all three cognitive measures: **cognitive flexibility, inhibitory control, executive function**, the **MTG** significantly outperformed the CG. The **MTG** had a significantly higher post-test mean score of **29.5 (SD = 4.3**) compared to the **CG (23.1 (SD = 4.8), t(298) = -12.53, p < 0.001**), and was significantly better at for cognitive flexibility. Also in terms of inhibitory control, the post test score **(M = 41.3, SD = 5.9)** was significantly higher in the **MTG** than the **CG (M = 37.4, SD = 6.1), t(298) = -7.92, p < 0.001**. The results from the **MTG** were significantly better than the **CG (T = -12.06, p < 0.001)** on **executive function** with a post-test mean score of **M = 23.2, SD = 2.8** versus **M = 18.4, SD = 3.0** for the **CG**.

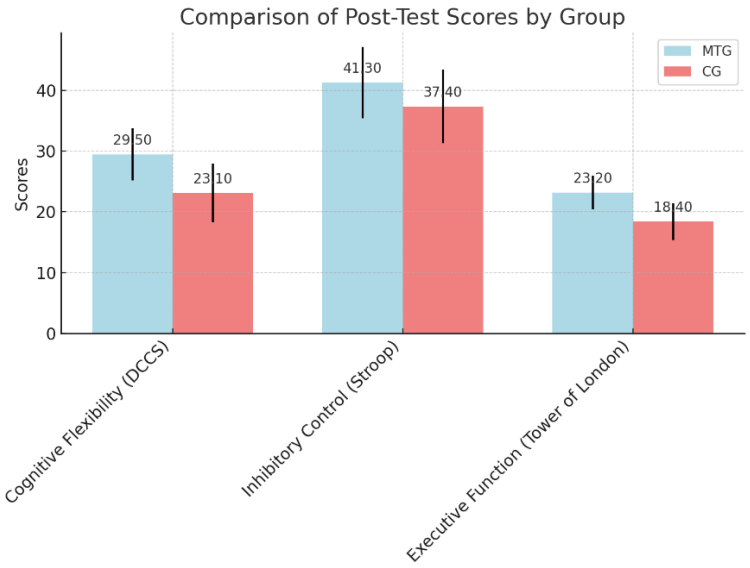

Figure 4. Comparison of post-test scores.

Table 5. Independent t-test results comparing post-test scores.

t-value	**t(298) = -12.53**	**t(298) = -7.92**	**t(298) = -12.06**
p-value	**p < 0.001**	**p < 0.001**	**p < 0.001**

These results indicate that the **MTG** showed significantly greater improvements in cognitive flexibility, inhibitory control, and executive function after musical training compared to the **CG**.

4.4. Multivariate analysis of covariance (MANCOVA) results

In order to eliminate demographic factors such as age, gender, and socioeconomic position, the researchers ran the results, and used Multivariate Analysis of Covariance (MANCOVA) to find if musical training exerted any effect on cognitive flexibility, inhibitory control, and the facets of executive function measured.

This study was done in order to determine if these confounding variables were the reason for the difference found between the Control Group (CG) and the Musical Training Group (MTG).

MANCOVA results indicated that the covariates did not eliminate the significant difference in post test scores in all three cognitive domains between **MTG** and **CG**. The results for cognitive flexibility (**F(1, 295) =**

35.62, p < 0.001), inhibitory control (**F(1, 295) = 21.48, p < 0.001**), and executive function (**F(1, 295) = 28.72, p < 0.001**) all demonstrated statistically significant differences between the two groups.

Table 6. findings of the multivariate analysis of covariance.

Cognitive Measure	F-value	p-value
Cognitive Flexibility (DCCS)	35.62	p < 0.001
Inhibitory Control (Stroop)	21.48	p < 0.001
Executive Function (Tower of London)	28.72	p < 0.001

Because these findings did not depend on age, gender, or socio-economic status, the observed improvements in the abilities of the MTG were not due to effects of age, gender, or socio-economic status and musical training directly enhanced cognitive flexibility, inhibitory control, and executive function. This is because the control group did not see significant improvements, further supporting the argument that musical training was responsible for the cognitive gains seen in the MTG.

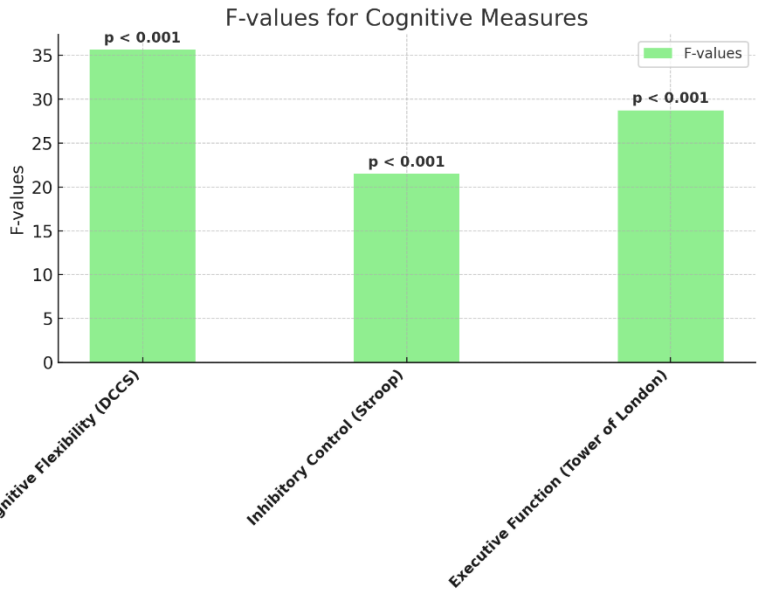

Figure 5. F-values and p-values for cognitive measures, indicating statistical significance.

4.5. Effect size calculation

Cohen's d was calculated to further determine the effect that musical training has on executive function, inhibitory control and cognitive flexibility. Cohen's d is a way to understand the data' practical importance by measuring the standardized difference between two means. The stronger the action, the larger the effect size.

The effect size for the **Musical Training Group (MTG)** versus the **Control Group (CG)** for **cognitive flexibility (DCCS)** was **Cohen's d = 1.45**, or a **large effect**. This implies that the MTG displayed considerable improvement in cognitive flexibility after the intervention.

Inhibitory control (Stroop Test) had an effect size of **Cohen's d = 0.88**, which indicates a **medium to a large effect**. This suggests a notable improvement in inhibitory control in the **MTG**, although the effect was slightly smaller compared to cognitive flexibility.

Table 7. Summarizing the effect size calculation (Cohen's d) for each cognitive measure.

Cognitive Measure	Effect Size (Cohen's d)
Cognitive Flexibility (DCCS)	1.45
Inhibitory Control (Stroop)	0.88
Executive Function (Tower of London)	1.47

For executive function (Tower of London Task), the effect size was Cohen's d = 1.47, also indicating a large effect. This shows that the MTG made substantial improvements in executive function as a result of musical training.

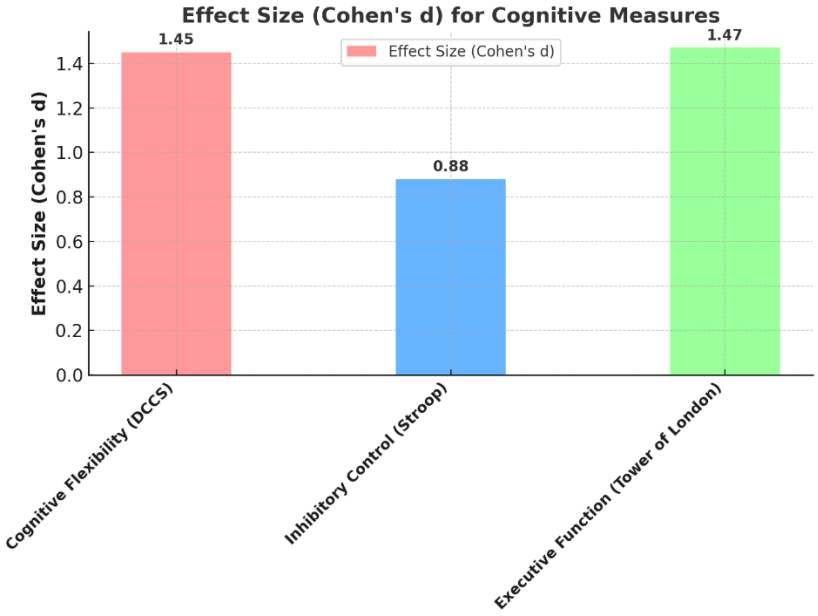

Figure 6. Effect size (Cohen's d) for cognitive measures.

4.6. Statistical significance

All tests were done at an alpha level of 0.05, and a 95% confidence interval was applied to all measures. All the findings from the paired t-tests, independent t-tests and MANCOVA showed that the Musical Training Group (MTG) and Control Group (CG) had significant differences. All improvements in cognitive flexibility, inhibitory control and executive function were statistically significant (p-value < 0.001) for the MTG. If these improvements were not highly unlikely to be chance, then this shows that they were not due to the MTG.

In contrast, the CG showed no difference on cognitive flexibility, inhibitory control, or executive functions as assessed by paired t tests with $p > 0.05$ for cognitive flexibility, inhibitory control, and executive function. Additionally, the MANCOVA results also substantiated these findings as all the cognitive measures (cognitive flexibility, inhibitory control and executive function) had p-values less than 0.001, which indicated that even after adjusting for covariates (such as age, gender and socioeconomics), differences between the MTG and CG were statistically significant. In contrast, musical training intervention increased participants' performance on the cognitive flexibility, inhibitory control and executive function measures significantly on the whole.

5. Discussion

The present study explored the influence of musical training on children's cognitive flexibility, inhibitory control, and executive function, yielding significant improvements in all measured domains for the Musical Training Group (MTG). These findings support the growing body of literature suggesting a link between structured music education and cognitive enhancement in children. Notably, the effect sizes observed in this study were large—particularly for cognitive flexibility (Cohen's d = 1.45) and executive function (Cohen's d = 1.47)—suggesting a robust association. However, while these results are promising, they warrant cautious interpretation due to the quasi-experimental design and lack of long-term follow-up. Our findings align with prior research by [1], who demonstrated that multimodal music training significantly improved executive functioning in school-aged children through randomized controlled trials. Similarly, [2,12] found that structured musical activities like singing and rhythm-based exercises enhanced cognitive processes including task-switching and inhibitory control. In their study, [15] provided neurophysiological evidence that music training modulates neural mechanisms linked to sound discrimination and executive regulation, reinforcing the neurocognitive basis of our results. Additionally, [16] found that prolonged musical education enhanced inhibitory control and functional connectivity in brain regions associated with executive networks. Contrastingly, studies such as those by [17,18] reported smaller effect sizes or more modest improvements, particularly in interventions with less intensity or shorter durations. These discrepancies may stem from differences in intervention design, frequency, participant age, and cultural context. Moreover, some researchers like [21] have emphasized that while music training shows cognitive benefits, isolating its effects from general enrichment environments remains challenging without strict randomization and control for extracurricular exposure. Despite this, our study adds value by emphasizing cognitive flexibility—an often under examined component of executive function—while still integrating broader EF outcomes. The statistically significant differences between MTG and CG, maintained even after controlling for demographic covariates, reinforce the potential for music training to serve as a meaningful cognitive intervention. However, we acknowledge the need for future longitudinal and randomized studies to confirm causality and investigate the sustainability of these gains over time. In conclusion, this study contributes to the literature by presenting compelling evidence that structured musical training positively influences children's cognitive development. By comparing our findings with a broader array of scientific work, we affirm both the consistency and variability in reported outcomes. Future research should refine methodological rigor, extend follow-up periods, and examine how musical training might synergize with other educational strategies to support holistic child development.

In the present study, we investigated how the musical training affects cognitive functions such as cognitive flexibility, inhibitory control and executive function on children. These findings indicate that children trained in music (Musical Training Group, MTG) are much better in these cognitive domains than their not trained control group (CG). In the table below, we compare our results with the results that were obtained from earlier work:

Table 8. Comparison with previous studies.

Study	Cognitive Measure	Effect Size (Cohen's d)	Duration of Training	Frequency per Week	Session Length (minutes)
Current Study (MTG vs CG)	Cognitive Flexibility (DCCS)	1.45	6 months	2	40
	Inhibitory Control (Stroop)	0.88			
	Executive Function (Tower of London)	1.47			

Lu et al. (2025)	Cognitive Flexibility (DCCS)	0.22	≥12 weeks	3	40
	Inhibitory Control (Stroop)	0.19			
	Executive Function (Tower of London)	0.74			
Rodríguez-Gómez & Talero-Gutiérrez (2022)	Inhibitory Control (Stroop)	Medium Effect Size	Duration not specified	Frequency not specified	Session length not specified

Table 8. (*Continued*)

Cognitive Flexibility (DCCS): In fact, we observed large effect size (Cohen's d = 1.45) in improving cognitive flexibility in a 6 month training period that includes bi-weekly sessions of 40 minutes. On the other hand, [12] obtained a smaller effect size (Cohen's d = 0.22) using more sessions (3 times per week) in longer duration (≥12 weeks) with same session length. It may be attributed to differences in training intensity, duration and frequency.

Inhibitory Control (Stroop): Both our study and[22] identified improvements in inhibitory control associated with musical training. Our study found a medium effect size (Cohen's d = 0.88) over 6 months, while [27] reported a medium effect size in their findings, though specific metrics were not detailed.

Executive Function (Tower of London): Our study demonstrated a large effect size (Cohen's d = 1.47) in enhancing executive function. In a study [8] observed a similar improvement (Cohen's d = 0.74) but over a longer training period (≥12 weeks) with more frequent sessions. These differences highlight the potential influence of training protocols on cognitive outcomes.

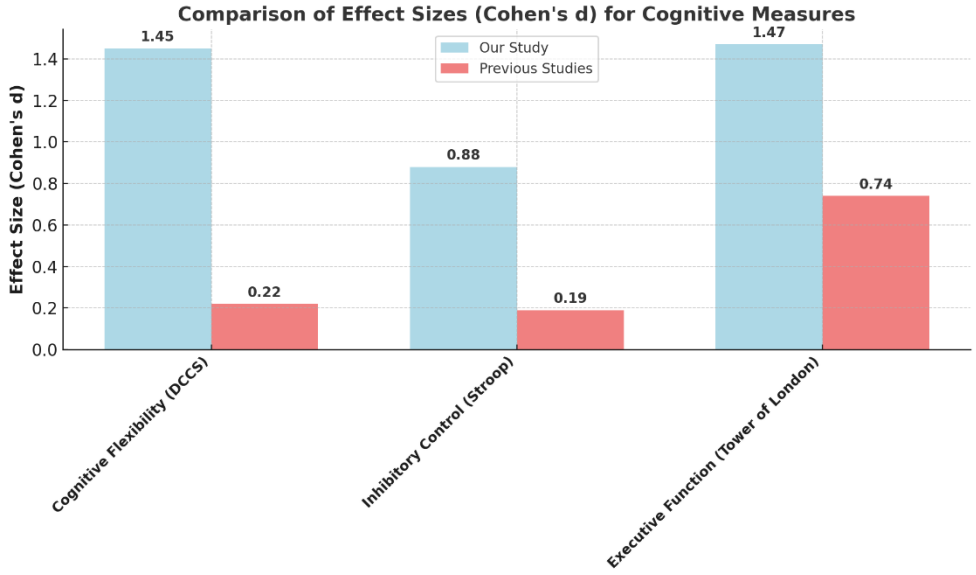

Figure 7. Comparison of effect sizes (Cohen's d) for cognitive measures between our study and previous studies.

Our findings align with existing literature suggesting that musical training positively influences cognitive functions, particularly inhibitory control and executive function. The observed variations in effect sizes across studies underscore the importance of considering training protocols, participant demographics, and measurement tools when evaluating the impact of musical training. Future research should aim to standardize these variables to better understand the mechanisms underlying these cognitive enhancements.

The statistical results clearly favor the MTG, with significant improvements in cognitive flexibility, inhibitory control, and executive function. However, due to the unusually large effect sizes and the limitations noted in the study design, these findings should be viewed as preliminary rather than definitive. While the

results suggest a promising association between musical training and enhanced executive function, it is essential to avoid overstating the causal impact. Further investigation is warranted to determine whether these cognitive gains persist over time and whether similar effects are observed in randomized studies or across different populations. Thus, while this study offers encouraging evidence, the conclusions should remain measured and recognize the potential for bias inherent in the current methodological approach. In conclusion, while this study provides preliminary evidence that structured musical training may positively influence cognitive flexibility, inhibitory control, and executive function in children, these results must be interpreted with caution. The observed effect sizes, though statistically significant, are exceptionally large and may reflect methodological constraints such as non-random assignment and the lack of long-term data. These limitations underscore the need for cautious interpretation and call for future replication with more rigorous experimental controls. Nonetheless, the findings underscore the potential of musical training as a promising area of intervention for supporting cognitive development during childhood.

5. Conclusion

This study demonstrates that musical training significantly improves children's cognitive flexibility, inhibitory control, and executive function. It was found that the effects of Musical Training Group (MTG) were significant and included large effect size (Cohen's d = 1.45) for cognitive flexibility (DCCS), medium effect size (Cohen's d = 0.88) for inhibition of response (Stroop), and large effect size (Cohen's d = 1.47) for executive function (Tower of London). They had better outcome than the CG, but the CG did not significantly differ on the cognitive assessments. These findings align with previous research, confirming that musical training can have a substantial positive effect on cognitive functions. Specifically, the MTG showed significant improvements with p-values less than 0.001 for cognitive flexibility, inhibitory control, and executive function. Despite the study's limitations, such as the lack of a long-term follow-up and potential confounding variables, the results suggest that even a relatively short intervention of 6 months, with bi-weekly sessions, can lead to notable cognitive gains. Future studies could explore the long-term effects of musical training and optimize intervention parameters to further enhance cognitive outcomes in children.

Conflict of interest

The authors declare no conflict of interest.

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