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Biological Basis of Music-Based Interventions to Improve Cognitive Function in Children

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ABSTRACT

Cognitive function refers to the wide range of mental processes involved in acquiring and applying information. Previous research has found that music improves multiple cognitive skills and provides developmental benefits to children. In this review, we found that music largely improves reading skills, mathematical skills, motor functions, and certain behaviors in children. We also further explored the existing research on the biological basis underlying these phenomena. For example, research has shown that music and reading activate overlapping brain regions, suggesting music enhances reading skills in children because it strengthens shared neural pathways. Similarly, music training has been demonstrated to improve spatial-temporal reasoning, an integral aspect of mathematical processing, due to overlapping brain regions. It has been suggested that both active music training and passive music training (Mozart Effect) can improve mathematical function by activating an underlying neural network that supports spatial-temporal reasoning. Studies using MRI and EEG techniques have also found that music training strengthens motor function by driving neurological changes in motor regions, a process called neuroplasticity. Finally, music training is hypothesized to enhance social communication due to music influencing changes in intrinsic brain connectivity; improve inhibitory control by accelerating the development of a more efficient inhibitory control network; and reduce internalizing disorders by counteracting the effects of dopamine transporter downregulation. This review provides valuable evidence for the use of music as an educational tool or therapy, with the potential to benefit both healthy children and those with cognitive or developmental disorders.

INTRODUCTION

Cognitive function refers to the extensive range of mental processes involved in acquiring and processing knowledge, perceiving, reacting, and making appropriate decisions (Tavares et al., 2023). It also refers to various high-level intellectual functions, such as memory, attention, language skills, comprehension, and more (Dhakal & Bobrin, 2025). These functions are facilitated by the corpus callosum, a bundle of nerves that connects the two hemispheres of the brain, playing a crucial role in the communication of information between the left and right hemispheres. This communication enables many cognitive functions, such as memory, language processing, problem-solving, and reasoning (*What's the Function of the Corpus Callosum?*, n.d.). The corpus callosum is a region of the brain that largely develops during adolescence, increasing approximately 1.8% per year between the ages of 3-18. In addition, the frontal lobe is responsible for many cognitive processes, such as executive function, attention, and memory (Maldonado & Alsayouri, 2025). Similar to the corpus callosum, the frontal lobe develops throughout adolescence and is fully developed during one's mid-20s (*Brain Development in Early Childhood*, n.d.). Thus, what a child is exposed to during adolescence plays a crucial role in their cognitive development (*Brain Development in Early Childhood*, n.d.).

Historically, it has been theorized that music plays a role in cognitive function, with this theory dating as far back as Plato and Aristotle, who hypothesized that music might contribute to the education of the youth (Ravasio, 2021). However, it wasn't until the publication of the article "Music and Spatial Task Performance" that sparked widespread interest in the theory that listening to music could improve cognitive function, since dubbed the Mozart Effect (F. H. Rauscher et al., 1993). It has been shown that music training involves a wide range of brain functions, ranging from motor processes to higher-order cognitive functions, resulting in behavioral, structural, and functional changes over time (Herholz & Zatorre, 2012). Since the skills associated with music training overlap with various other cognitive functions, research has been conducted to determine if musical expertise transfers to other domains, both related and unrelated to musical training. Data has not only demonstrated a correlation between musical training and near-transfer domains, such as auditory processing, but also a relationship with far-transfer areas. (Slater et al., 2015). For instance, multiple studies have suggested that music enhances reading abilities in children by improving phonological awareness, an essential component of reading (Degé & Schwarzer, 2011; Hogan et al., 2005) In addition, given that music has been shown to improve spatial-temporal reasoning, an integral aspect of mathematics, it has been suggested that music improves mathematical abilities (Holmes & Hallam, 2017). Spatial-temporal reasoning refers to the ability to understand and manipulate objects in both space and time. Children use spatial-temporal reasoning to visualize geometric shapes, understand the relationships of numbers, create patterns, and improve their problem-solving skills. Up until now, literature reviews have only focused on the effect of music on speech and behavioral inhibition, or children with neurological injury. However, this manuscript provides a broad review of how music-based therapies impact various cognitive functions in children without neurological injury. It also seeks to explore the biological mechanisms underlying music's impact on motor function, reading, mathematics, and behavior, as this has been previously underexplored. Given that each of these cognitive functions activate regions in the brain that are also activated by music, improvements might be a result of music strengthening these connections or driving neurological changes. This study demonstrates the importance and implications of music education on the development of children, especially those with cognitive disorders. Promoting the availability of music resources could yield many benefits for children by improving various cognitive abilities as well as behavior.

MUSIC INTERVENTIONS TO IMPROVE MOTOR FUNCTION

Various studies have explored how musical training impacts motor development in children, uncovering an improvement in both fine finger motor skills as well as gross motor abilities following musical training. One longitudinal study compared 15 children (average age of 6.32 years), who received weekly 30-minute private keyboard lessons for 15 months, with 16 control children (average of 5.90 years), who did not participate in formal music training (Hyde et al., 2009). Because this study took a quasi-experimental approach, definitive casual conclusions cannot be drawn. Children underwent a series of tests to assess fine finger motor skills as well as an anatomical MRI before and after the intervention. The findings showed that the children in the instrumental group demonstrated significantly greater improvement in performance of right-hand motor function compared with those in the control group ($p=0.01$), and that this difference approached significance for the left hand ($p=0.06$). One limitation that the authors acknowledge is the possibility of pre-existing biological differences between the children, such as a predisposition to music, making it difficult to determine whether the observed improvements were a direct result of the music training.

One cross-sectional study compared 31 children between the ages of 6 and 11, among whom 16 were placed in a music group and 15 were placed in a non-music group (da Silva et al., 2022). Children in the music group had received between one to three years of music training prior to the collection of data, whereas the non-music group did not receive any musical training. Because this study compared pre-assigned groups and didn't take baseline measures, the results are correlational and thus, causal evidence cannot be drawn. EEG data were collected while each participant was executing various tasks. These included the box-and-block task, requiring children to transport a block over a partition for 1 minute, a singing task, and a rhythm task. Results found that those with musical training scored higher in overall motor quotient levels ($p<0.03$), temporal orientation ($p<0.01$), and balance ($p = 0.03$) compared to those in the control group. However, because this was a cross-sectional study, one limitation is the absence of baseline measures, making it difficult to determine whether music training was the reason for the observed differences or if these differences were already present.

Similar findings were reported in a randomized control trial investigating the impact of a music-and-movement based education program on children's motor skill development (Gencigör & Akın, 2024). Because of the randomized control trial design, causal conclusions about the effect of a music based exercise program on the motor skill development of children can be drawn. This study randomly assigned 78 seven-year old students to an experimental group or a control group and assessed their locomotor and object control abilities before and after the intervention. Students in the experimental group participated in 40-minute music-and-movement exercises three times per week for eight weeks, while the control group did not engage in any exercises. Results found a statistically significant difference between the post-test scores of the two groups ($p < .001$) with a large effect size, indicating an improvement in motor skills following musical training. One limitation of this study was the short 8-week intervention period, making it difficult to determine long term effects of this program.

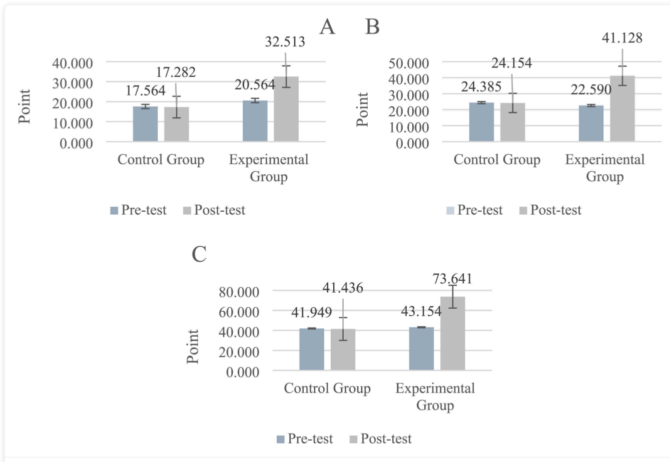

Figure #1: Participants' (A) Object Control, (B) Locomotor Skills, and (C) Test of Gross Motor Development-2 Total scores by group and test time, showing a statistically significant difference between the post-test scores of the two groups. (Gencigör & Akın, 2024)

While all of these studies suggest that music training improves motor function in children, they vary in the degree of strength they provide for this relationship. For example, the study by da Silva et al. can only provide correlational evidence since it didn't take baseline measures and compared pre-assigned groups. The quasi-experimental study by Hyde et al., however, provides stronger evidence of a relationship between music and motor function improvement since it employed an intervention and a comparison group. Ultimately, however, the study by Gencigör & Akın provides the strongest causal evidence because of its randomized control trial design. Together, these studies demonstrate that while the link between music and motor development is well supported, the rigor of the study design must be evaluated in order to determine the extent to which these results can be determined as causal.

Engaging in musical activities requires activation of regions in the brain associated with motor functions. This includes the cerebellum, premotor cortex, and the basal ganglia (Toader et al., 2023). Notably, in these motor function regions, musical training has been shown to be capable of driving neurological changes, a phenomenon called brain plasticity. Brain plasticity refers to the brain's process of modifying its functions and structures in response to intrinsic and extrinsic stimuli (Puderbaugh & Emmady, 2025). This effect is evidenced by a more pronounced, developed motor region in individuals with musical training compared to non-musicians, as discovered in a study using voxel-based morphometric MRI analysis (Gaser & Schlaug, 2003). The development of this region through musical training provides an explanation for the superior motor functions of individuals with musical training compared to those without such training.

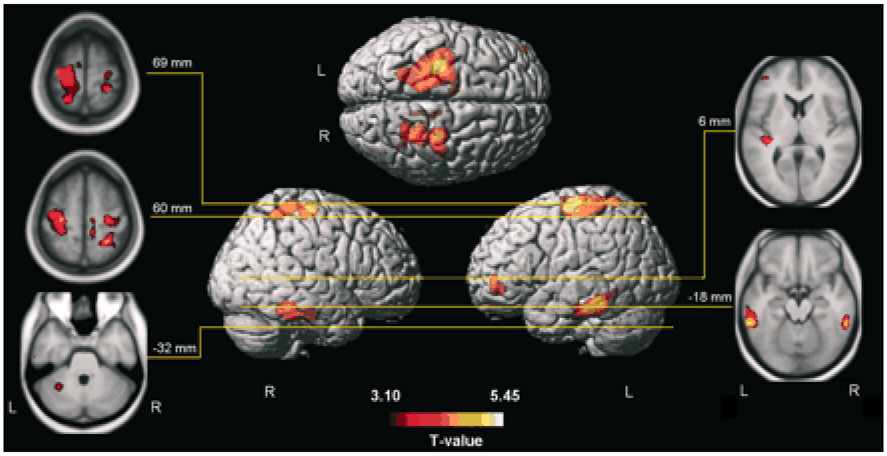

Figure #2: MRI results showing brain regions where grey matter volume was significantly correlated with musician status, including the primary motor area, somatosensory area, premotor areas, anterior superior parietal areas, left Heschl's gyrus, and the inferior temporal gyrus bilaterally. (Gaser & Schlaug, 2003)

In addition, EEG data provide evidence that children with musical training have higher gamma peak frequencies in the prefrontal, premotor, and supplemental motor cortices compared to the children without musical training (da Silva et al., 2022). Gamma peak frequency refers to the specific frequency within a gamma band where the strongest brainwave activity is detected. Enhanced activity in these specific regions supports the theory that musical training may influence anatomical changes within the motor regions of the brain, thus improving motor function.

MUSIC INTERVENTIONS TO IMPROVE READING SKILLS

A number of studies have focused on using music-based interventions to improve reading skills among children, specifically by refining phonological and phonemic awareness or broadening vocabulary. A randomized control study, capable of providing causational evidence, examined this effect in 46 children with dyslexia who were pseudo-randomly sorted to either a music or painting training group for two hours per week for seven months (Flaugnacco et al., 2015). Assessments evaluated linguistic, musical, reading, and phonological abilities before and after training. Findings found that while both groups demonstrated overall improvement in reading, the music group outperformed the painting group in various reading tasks. For example, one test showed 50% fewer musically trained children were considered 'very poor performers' in comparison to the painting group. Additionally, while both groups had an improvement in phonological awareness, the music group demonstrated a greater improvement in the accuracy of reading pseudowords, outperforming the painting group in tasks such as pseudo-word repetition and phenome-blending. Importantly, the authors acknowledge that their sample size was smaller than what is usually advised for a pilot study, which may limit the generalizability of the study.

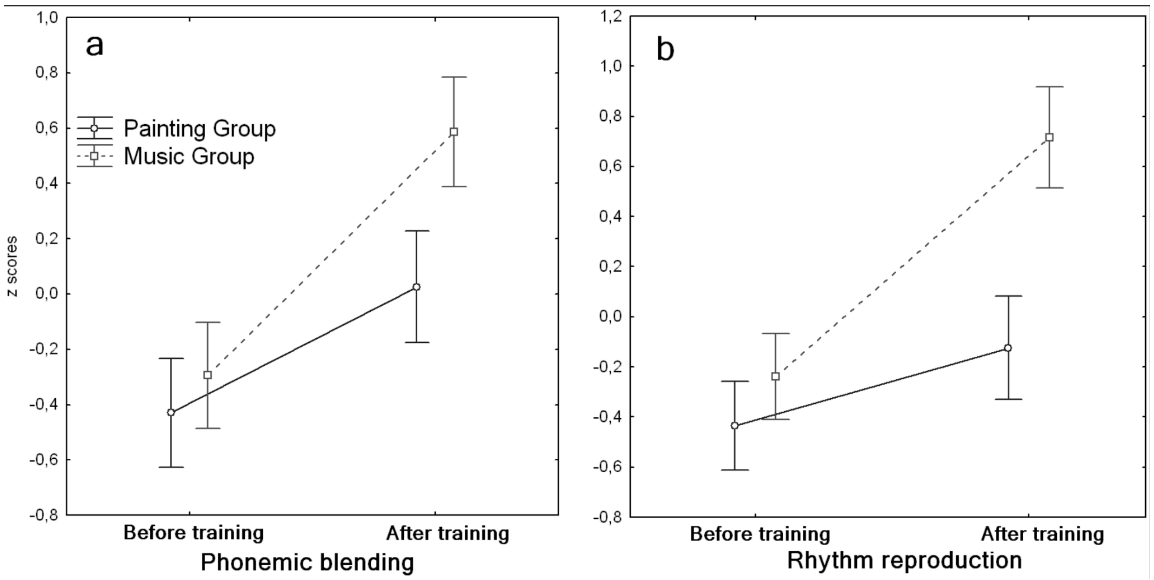

Figure #3: Performance in phenome blending (a) and rhythm reproduction (b) tasks before and after music or painting training, demonstrating the music group's outperformance of the painting group. (Flaugnacco et al., 2015)

Another study investigated whether music training impacts phonological awareness and word learning in 32 native French-speaking children (8-12 years old), half of whom had practiced music for several years (Dittinger et al., 2017). Using a correlational design, music and vocabulary-related outcomes were measured through several tasks involving unfamiliar Thai words paired with images. During a couple of the tasks, researchers recorded electroencephalogram (EEG) data. This study found a statistically significant correlation between musical aptitude and word learning, reflecting that musically trained children attained superior word learning of words, evidenced by fewer errors made by this group on the semantic task. Notably, although this study had a small sample size, the authors claim that because the main effects were statistically significant in the music group and not in the control group, between-group differences were clear. Another limitation in this study is that they weren't able to isolate music training as the sole cause of the observed improvement in word learning as other non-music related factors could have played a role.

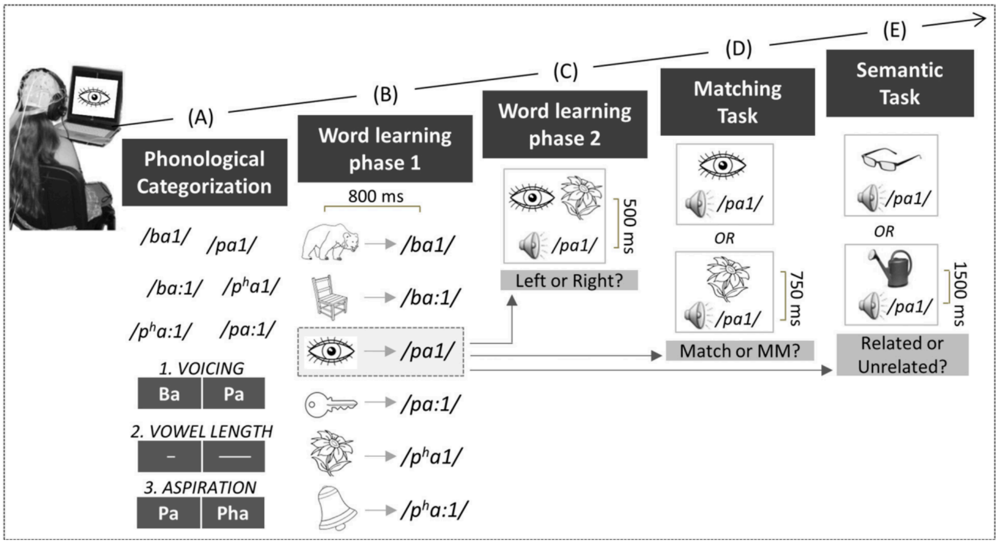

Figure #4: The tasks that the children completed. First, they learned the meaning of each unfamiliar Thai syllable by associating a picture with each word (A, B, C). Then, to evaluate how effectively they had learned each word, they underwent a Matching Task (D) and a Semantic Task (E), while EEG data was collected. (Dittinger et al., 2017)

A cross-sectional study explored the relationship between music abilities, phonological awareness, and reading skills in 100 children aged four to five (Anvari et al., 2002). As a correlational study, this study only provides associative relationships rather than causal ones. Results found that phonological awareness was strongly correlated to reading abilities and that musical abilities were associated with phonemic awareness. This suggests that the auditory processes involved in perceiving music are related to those used for phonological processing, and consequently, reading development. On top of that, regression analysis revealed that after the variance attributable to phonological awareness was controlled for, the music ability of 4-year-olds accounted for a significant portion of variance in reading scores, while pitch awareness in 5-year-olds similarly explained significant differences in reading performance. These findings suggest that phonological awareness does not completely explain the connection between music skills and reading abilities, indicating that music perception may rely on distinct auditory or cognitive processes related to reading skills that only partially overlap with those involved in phonological processing. One limitation the authors of this study acknowledge are the inconsistent findings about the relationship between rhythm and reading both within their study and in prior studies, making it difficult to identify which aspects of musical training contribute to reading skills. In addition, because this study was correlational, it only provides relationships rather than evidence that music training directly improves reading skills.

While all three of these studies support a relationship between musical training and reading development, there are important differences between them. Notably, the study by Flaugnacco et al. was the only randomized control trial. This means that while this study is able to provide causal evidence, the other two studies are only able to provide correlational evidence. In addition, each study evaluated different demographics: Flaugnacco et al. assessed children with dyslexia, Dittinger assessed children between the ages of 8-12, and Anvari assessed children between the ages of 4-5. Thus, these differences suggest that the strength and generalizability of these findings vary depending on the study.

Various hypotheses have been proposed regarding the biological basis behind this phenomenon. While reading acquisition requires the visual processing of a written language, the development of phonological awareness is vital for learning how to read. When children are able to identify the individual sounds in a word, they can connect these phonemes to their corresponding written letters. Since it has been shown that phonemic awareness correlates with reading development, this suggests a strong link between auditory processing and reading ability (Anvari et al., 2002).

MRI research has demonstrated that multiple brain regions that are involved in reading and phonological tasks are also activated by musical training. Regions involved in reading and phonological tasks include several regions of the temporal lobe, the inferior frontal region, and the left ventral occipitotemporal cortex. Research has also shown that stronger connectivity between the superior temporal gyrus and inferior frontal gyrus is associated with better reading ability (Barouch et al., 2022; Wang et al., 2021, 2023). Certain music activities also result in activation of these regions. For example, rhythm tasks involve the superior temporal gyrus, the supplementary motor area, and the pars opercularis within the inferior frontal gyrus (Sakreida et al., 2018). Similarly, playing music involves the temporal and inferior frontal areas, as well as certain motor regions (Olszewska et al., 2024). Given that reading and music playing activate overlapping brain regions, this suggests that an improvement in music abilities may subsequently lead to a strengthening of reading by reinforcing the connectivity of these areas through repeated activation. Furthermore, in a study by Dittinger, EEG signals associated with word learning were faster among children with a music training background than those without (Dittinger et al., 2017). These findings suggest that music training may result in a generalized increase in brain plasticity, resulting in more rapid acquisition of new abilities such as reading.

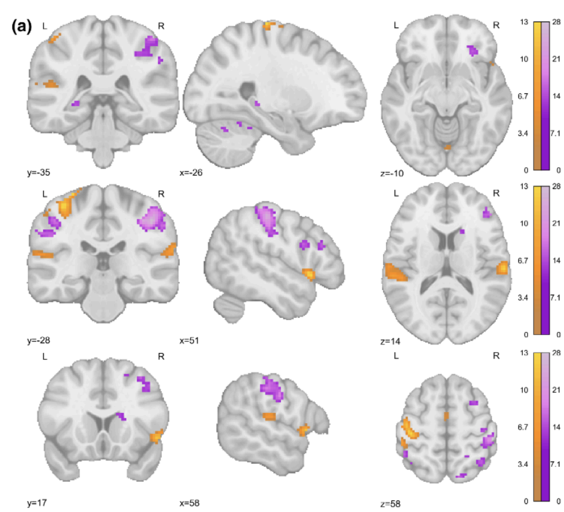

Figure #5: This show the brain regions that are activated by music training. Orange indicates the regions that are initially activated when playing music, while purple indicates the regions that become activated after music training for half a year. (Olszewska et al., 2024)

MUSIC INTERVENTIONS TO IMPROVE MATHEMATICAL ABILITY

Studies that explored the correlation between music-based interventions and mathematical skills among children revealed an improvement in problem-solving strategy, mathematical ability, and arithmetic after music training. One study integrated 45-minute music activities with the regular math lessons of 46 first and third grade students each week for a period of five weeks (An et al., 2013). Because of this study's quasi-experimental design, it lacks random assignment, meaning that these results do not provide definitive causal evidence. Each music-mathematics activity combined a key mathematical concept with music composition and playing activities. Before the intervention began and after each music-mathematics lesson, the Model-Strategy-Application (MSA) assessment was administered to each student to determine their mathematical problem-solving ability. Results found that both the first and third grade students showed statistically-significant improvements in all three mathematical areas (model, strategy, and application) after the intervention, indicating that the music-integrated mathematics lessons positively influenced students' mathematical problem-solving ability. One limitation that the authors acknowledge is the possibility of the Hawthorne Effect impacting the results, a possibility they attribute to the 5 week intervention period and the novel teaching strategy used by the teachers. Additionally, the use of cluster sampling to select a single class of students limits the generalizability of the findings to other elementary schools.

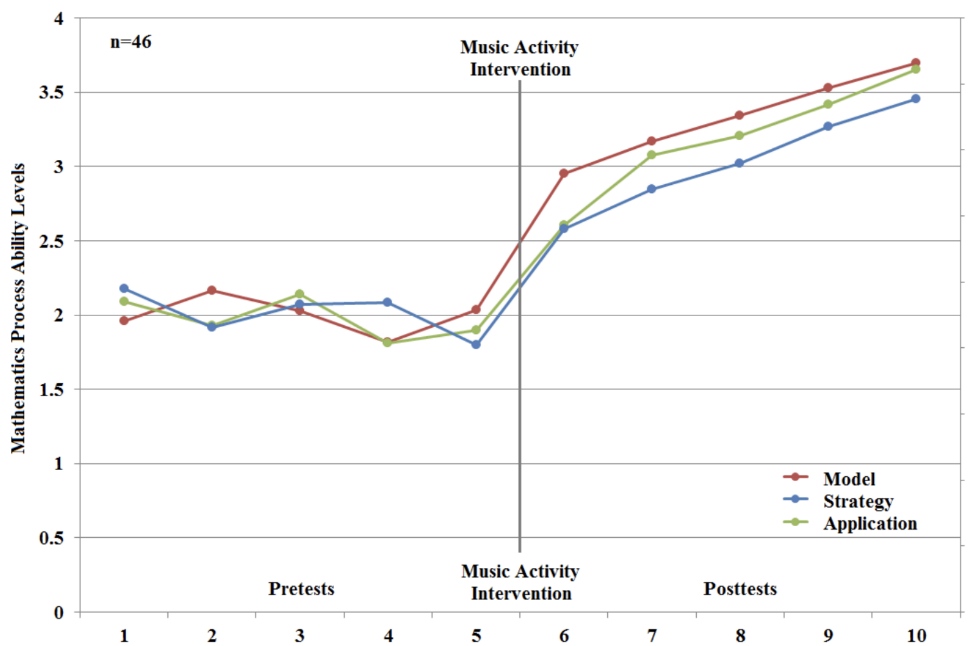

Figure #6: Graph comparing average mathematical ability level in the areas of model, strategy, and applications, both before and after the music activity intervention for first and third-grade students. This shows the improvements in all three mathematical areas following the intervention. (An et al., 2013)

A quasi-experimental study examined whether Indian Carnatic music training impacted mathematical abilities in 156 children aged 5-8 (Raja & and Bhalla, 2021). The study's use of a quasi-experimental design, in which the groups were pre-assigned, limits interpreting conclusions as definitively causational. Students were assigned to either an experimental group, who received four weely 45-minute music classes for 20 weeks, or a control group, who did not receive any music training. To assess mathematical ability, both groups were administered the Test of Early Mathematics Ability-3 (TEMA-3) before and after the music intervention. Results revealed that students in the experimental group had significant improvement in their post-intervention mathematics scores, while the control group had no significant improvement. Interestingly, when compared to older age groups, the youngest age groups had a more significantly improved performance. Although an explanation for this phenomenon was not provided in this manuscript, they acknowledged that the faster brain development during early childhood may have contributed to this difference. One limitation of this study was that certain external factors, such as mathematics tutoring or music listening at home, could not be controlled for, and thus, could have possibly impacted the results.

The previously described cross-sectional, correlational study by Anvari et al. (which administered various tests to 4-5 year old children to investigate the relationships between music perception, phonological awareness, and reading ability) also explored how other cognitive variables, such as mathematical ability, digit span, and vocabulary, contributed to the associations between music and reading (Anvari et al., 2002). Mathematical ability was assessed by having participants conduct four mathematical problems (two involving addition and two involving subtraction) through the lens of a story. Regression analysis demonstrated that mathematical ability did not account for the relationship between music perception and reading skills, suggesting that improvement in reading skills following music training was not due to changes in mathematical ability. However, this study did not directly evaluate if music training itself influenced mathematical ability.

While all of these studies explore the relationship between music training and mathematical ability, they differ in their methodology, and importantly, their strength. For example, the cross-sectional design of the study by Anvari et al. only allows correlational conclusions to be drawn. On the other hand, the quasi-experimental studies by An et al and Raja & Bhalla provide stronger evidence of a relationship between music and mathematical ability because of their inclusion of an intervention. That being said, definitive causal evidence is not able to be drawn from them because they lack random assignment, an essential factor for establishing causality.

The ability to execute math problems requires a host of functions, ranging from motor abilities to fact retrieval. However, since arithmetic and spatial processing are key aspects of mathematical ability, the impact of music on these specific components is an important area of exploration (Peters & De Smedt, 2018). There is an established relationship between spatial reasoning and early mathematical skills (Mix & Cheng, 2012). This is because children use spatial-temporal reasoning to visualize geometric shapes, comprehend the relationships between numbers through number lines or graphs, problem solve, and create patterns. All of these skills contribute significantly to improving a child's understanding of mathematical concepts. (Raja & and Bhalla, 2021). In addition, various studies have found that music training has a direct relationship with spatial-temporal reasoning, thus leading to an improvement in mathematical abilities (Holmes & Hallam, 2017; F. Rauscher et al., 1997).

An alternative theory suggests that simply listening to music improves spatial-temporal reasoning, commonly referred to as the “Mozart Effect” (F. H. Rauscher et al., 1993). This theory was established after behavioral experiments revealed an improvement in spatial reasoning in college students after hearing Mozart’s sonata. A possible explanation for this is that there is an overlap in cortical regions activated while listening to Mozart and those associated with spatial-temporal reasoning, such as the dorsolateral pre-frontal cortex (DPC), occipital cortex, and the cerebellum. An fMRI study showed that there was a significantly greater number of regions activated while listening to Mozart than when listening to 1930s piano music (Bodner et al., 2001). The regions showing greater activation during Mozart were the DPC, frontal cortex, occipital cortex, and the cerebellum, indicating the involvement of a neural cirtuit associated with spatial-temporal reasoning. This effect was also investigated by having participants perform a task involving spatial-temporal reasoning prior to and after listening to Mozart while undergoing EEG (Sarnthein et al., 1997). Temporo-parietal and prefrontal cortex activity was found during the spatial-temporal reasoning task. After listening to Mozart short-term, there was an increase in synchronized activity recorded on EEG in areas associated with spatial-temporal reasoning. Specifically, this was found in the left temporo-parietal lobe and the prefrontal cortex. This finding also correlated with improved performance on the spatial-temporal reasoning task following Mozart listening, though the effect was limited to a small number of patients and was marginal.

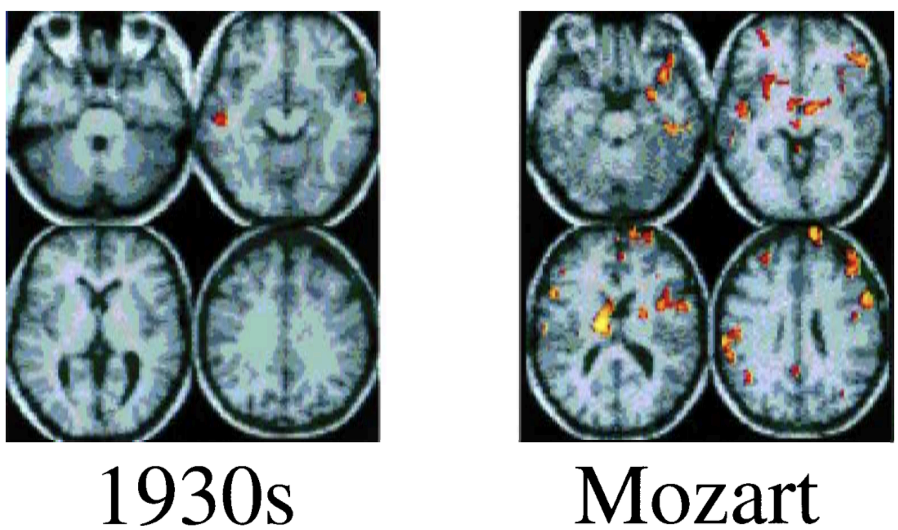

Figure #7: fMRI imaging data illustrating the cortical regions significantly activated in a subject while listening to 1930s piano music compared with Mozart’s Sonata. (Bodner et al., 2001)

Additionally, fMRI studies showed that certain regions involved in arithmetic overlap with regions activated by music. For instance, regions involved in arithmetic include the intraparietal sulcus, which supports the perception of numbers and performance of arithmetics; the superior parietal lobe, which is associated with the visuo-spatial aspects of numerical processing; and the supramarginal gyrus, which facilitates the consolidation of information during numerical problem solving in children (Menon, 2016; Peters & De Smedt, 2018; Popescu et al., 2019; Schel & Klingberg, 2017). Overlapping regions activated with music tasks include the left supramarginal gyrus, which is involved in encoding auditory information, and the bilateral, medial, and right superior parietal cortex, which contribute to coordinating the spatial and temporal aspects of music performance (Harris & de Jong, 2015; Kausel et al., 2020; Stewart et al., 2003). Since music and mathematical skills activate overlapping regions, this indicates that an improvement in musical skills may strengthen certain connections and pathways involved in mathematical processing through various musical activities, such as Carnatic vocal music training and music-mathematics integrated activities.

MUSIC INTERVENTIONS TO IMPROVE CERTAIN BEHAVIORS

Some educators have tested the use of music training to improve communication, inhibitory control, and internalizing behaviors in specific populations of children. One study evaluated the impact music had on social communication and brain connectivity in children with Autism Spectrum Disorder (ASD) (Sharda et al., 2018). This study was a randomized control trial, meaning it provides strong causal evidence that music training improves social communication and brain connectivity in children with ASD. 51 children with ASD (ages 6-12) were assigned to either a music intervention group or a non-music intervention group, each receiving weekly 45-minute individual sessions for 8-12 weeks. Before and after the intervention, social communication was evaluated with several assessments, and resting-state functional connectivity was measured with a resting-state fMRI (rsfMRI). Results found that after the intervention, the music group had improved communication scores, specifically in pragmatics, reduced inappropriate behaviors, and better social relations and interests. Limitations of this study include the relatively small sample size, which limits the generalizability of these findings, and the short intervention period, which prevents long term outcomes to be measured. These improvements in social function may be due to music's ability to alter intrinsic brain connectivity. rsfMRI data found that the music group had increased resting-state functional connectivity between the bilateral primary auditory cortices and subcortical regions, as well as between the bilateral primary auditory cortices and fronto-motor regions. In addition, they found a reduction in over-connectivity between auditory and visual-association areas, regions often over-connected in individuals with autism. These regions are significant because of their association with verbal and social communication skills in individuals with autism. Statistical analysis indicated that the changes in neural connectivity in the music group were related to the improvements in communication skills. Thus, this suggets that music intervention may alter intrinsic brain activity and connectivity, which then leads to improved communication in children with ASD.

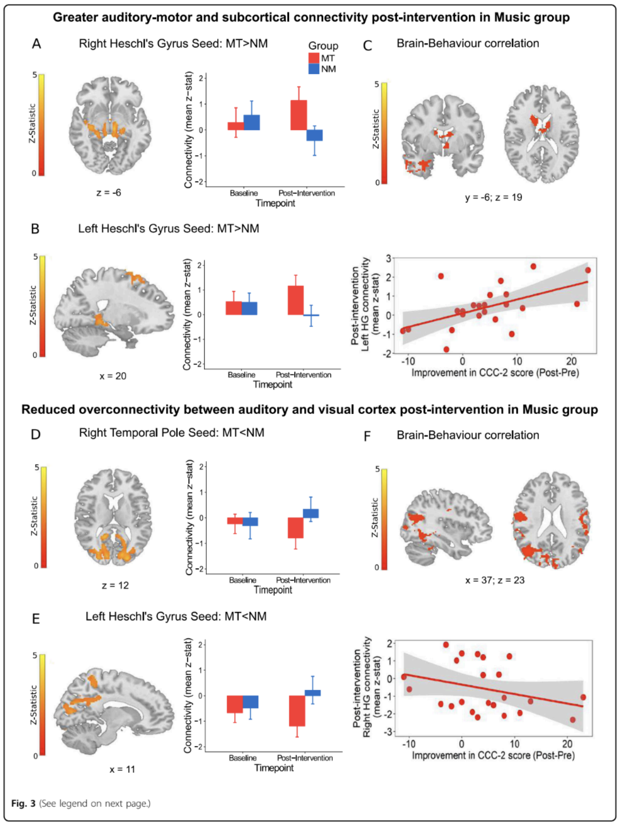

Figure #8: The upper panel displays brain regions showing increased resting-state functional connectivity after the intervention in the Music group compared to the Non-music group. This includes connections between the (A) Right Heschl's gyrus and subcortical regions and (B) left Heschl's gyrus and fronto-motor regions. (C) Connectivity between auditory regions and subcortical thalamic and stratial areas following the intervention was positively associated to improvements in communication in the Music group. The bottom panel displays brain regions with decreased resting-state functional connectivity after the intervention in the Music group compared to the Non-music group. This includes connections between the (D) right temporal pole and occipital regions and the (E) left Herschl's gyrus and the bilateral calcarine and cuneus regions. (F) Connectivity between auditory and visual sensory cortices following the intervention was negatively associated to improvements in communication in the Music group. (Sharda et al., 2018)

Another study investigated how orchestral music training enhances inhibitory control and reduces hyperactivity, inattention, and impulsivity in children (Fasano et al., 2019). Because this study includes a control group and an intervention, but didn't randomly assign the groups, it is a quasi-experimental study. This means definitive causal evidence cannot be drawn from these results. The study included 113 children (ages 8-10), with 55 children participating in a three month orchestral program, while the remaining 58 did not receive musical training. Pre- and post-tests included a Walk-No-Walk stop-signal test, an impulsivity control test, and a rating scale assessing inattention and hyperactivity-impulsivity, completed by both the participant and their teacher. Results revealed that the children who participated in the orchestral program had improved performance in the Walk-No-Walk test, which requires sustained attention, selective attention, and inhibition. Although the intervention did not have any significant effect on inattention and impulsivity, hyperactivity-impulsivity was found to have increased in the control group while remaining stable in the music group, as measured on the self-reported scale. The teacher rating scale reported a decrease in both groups in inattention, but no significant difference between them. On top of the absence of randomization to the groups, the study also had to cut the intervention period short to ensure that the post test results could be gathered before the end of the school year. This poses a another limitation because it is possible that the results did not capture the full effect of the music program. That being said, the improvement in inhibitory control may be explained by music training's influence on the development of the inhibitory control network. In adolescents, inhibitory control is regulated by a network that develops from a dispersed, posterior network into a more concentrated, frontal network with age. Younger brains rely more on posterior regions in order to compensate for underdeveloped frontal regions. In adolescents, this includes posterior regions such as the bilateral precuneus, left angular gyrus, right middle temporal gyrus, and the middle frontal gyrus. As they mature, the area regulating inhibitory control is refined into a more frontal, right-based network that consists of regions such as the right ventrolateral prefrontal cortex, right parietal lobe, right dorsolateral prefrontal cortex, and right inferior frontal gyrus (rIFG) (Kang et al., 2022). Specifically, in one 5-year longitudinal study, inhibitory control was compared between children involved in music programs, sports programs, and no extracurricular activities (Hennessy et al., 2019). Inhibition was tested with a range of tests conducted while participants underwent an MRI. A statistically significant improvement in inhibitory control was found among children who underwent music training. After 4 years, it was additionally found that differences in brain activity between musicians and the other groups were only observed in the right IFG. This suggests that music training could promote the earlier development of brain networks associated with inhibitory control during childhood, as the rIFG is a region associated with inhibitory control in adults and is not as commonly activated in children. Thus, this indicates music training may accelerate the development of a more efficient inhibitory control network, which provides an explanation as to why children who recieve musical training have been found to have superior inhibitory control in comparison to those who do not.

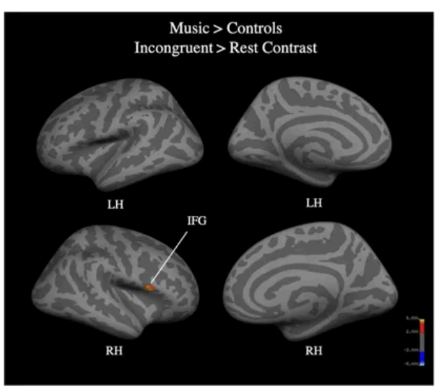

Figure #9: MRI results showing that musicians exhibit significantly greater activation of the right inferior frontal gyrus while engaging in an inhibition task after four years in comparison with the controls. (Hennessy et al., 2019)

One meta-analysis evaluated literature regarding the effectiveness of music-based interventions in reducing internalizing symptoms among children and adolescents with either pathological depressive symptoms or pathological anxious symptoms (Geipel et al., 2018). 1,089 papers were initially screened, but ultimately, five studies where chosen. Two were randomized controlled trials, two were quasi-randomized controlled trials, and one was a controlled trial. Four studies included participants who demonstrated depressive symptoms, while the other study focused on individuals with anxiety disorders. Although the studies utilized various approaches, results indicated that overall, music-based interventions were generally effective in reducing internalizing symptoms. In two trials, the experimental group had a significant improvement in internalizing symptoms compared to the control group. The other trials revealed a reduction of internalizing symptoms, but with no significant difference between the experimental group and the control group. The authors acknowledge various limitations of this meta-analysis, including a small sample size, since only five papers were included; poor methodology used by the studies, indicated by high risk of bias assessment; and highly disparate study designs. Thus, implications from this study must be drawn with caution. That being said, one possible explanation for the reduction in internalizing symptoms, as indicated by this study, is the influence of music on the dopamine system. Among those with Major Depressive Disorder (MDD), anhedonia and depressed mood are two distinguishing symptoms. Anhedonia is characterized by the inability to experience pleasure in activities that were once enjoyable. This disorder has been associated with disruptions in the dopamine (DA) system, which is critical for reward motivation and responsiveness to stimuli. It has also been demonstrated that the DA system gives incentive value to stimuli, transforming an enjoyment for a reward into a drive to achieve it, aligning with the diminished lack of motivation associated with MDD. This lack of dopamine has been reflected in Positron Emission Tomography (PET) studies that show significantly lower DA transporter (DAT) binding among patients with MDD in comparison with healthy subjects. It has been found that a chronic depletion of dopamine leads to this drop of DAT density, known as downregulation (Belujon & Grace, 2017). Thus, music may help counteract the effects of dopamine transporter downregulation by promoting dopamine release and possibly enhancing the responsiveness of existing dopamine receptors (Ferreri et al., 2019).

It is important to note that the studies and biological bases outlined in this section focus on different behaviors in specific populations. Namely, the study by Sharda et al. investigated how music influenced communication in children with Autism Spectrum Disorder; the study by Fasano et al investigated how music training influenced inhibitory control in children aged 8-10; and the study by Geipel et al. evaluated literature to investigate how music influences internalizing symptoms among children and adolescents with either pathological depressive symptoms or pathological anxious symptoms. Ultimately, while each of these studies support the relationship between music and the improvement of certain behaviors, generalizations beyond their respective populations should be drawn with caution.

CONCLUSION

This systematic review aimed to assess the impact of music-based interventions on various cognitive domains in children. The evidence found in these papers largely supports the role of music in enhancing cognitive function by improving motor functions, strengthening phonological awareness and reading skills, boosting temporal reasoning and mathematical skills, and enhancing certain behaviors in children. Evidence suggests that these phenomena are due to the overlapping neural regions involved in the listening to or learning of music and various cognitive functions. Imaging and EEG data indicate that music promotes neuroplasticity and a strengthening of connections involved in certain cognitive skills. Music's capacity to improve cognitive skills and provide developmental benefits has been relatively well established in existing research. This connection emphasizes the importance of music in educational settings and highlights how it may be used as a therapeutic tool for children with behavioral or cognitive dysfunction. Although some evidence points to a causal connection between music and improved cognitive function, this connection remains largely theoretical in nature due to limited research in this area. Thus, further research is necessary to better understand the biological basis of this phenomenon in order to continue to develop these hypotheses.

REFERENCES

An, S., Capraro, M. M., & Tillman, D. A. (2013). Elementary Teachers Integrate Music Activities into Regular Mathematics Lessons: Effects on Students' Mathematical Abilities. *Journal for Learning through the Arts*, *9*(1). https://doi.org/10.21977/D99112867

Anvari, S. H., Trainor, L. J., Woodside, J., & Levy, B. A. (2002). Relations among musical skills, phonological processing, and early reading ability in preschool children. *Journal of Experimental Child Psychology*, *83*(2), 111–130. https://doi.org/10.1016/S0022-0965(02)00124-8

Barouch, B., Weiss, Y., Katzir, T., & Bitan, T. (2022). Neural Processing of Morphology During Reading in Children. *Neuroscience*, *485*, 37–52. https://doi.org/10.1016/j.neuroscience.2021.12.025

Belujon, P., & Grace, A. A. (2017). Dopamine System Dysregulation in Major Depressive Disorders. *International Journal of Neuropsychopharmacology*, *20*(12), 1036–1046. https://doi.org/10.1093/ijnp/pyx056

Bodner, M., Muftuler ,L. Tugan, Nalcioglu ,Orhan, & and Shaw, G. L. (2001). fMRI study relevant to the Mozart effect: Brain areas involved in spatial–temporal reasoning. *Neurological Research*, *23*(7), 683–690. https://doi.org/10.1179/016164101101199108

Brain Development in Early Childhood. (n.d.). Retrieved February 23, 2025, from https://www.luriechildrens.org/en/blog/early-childhood-brain-development-and-health/

da Silva, K. S., Luvizutto, G. J., Bruno, A. C. M., de Oliveira, S. F., Costa, S. C., da Silva, G. M., Andrade, M. J. C., Pereira, J. M., Andrade, A. O., & de Souza, L. A. P. S. (2022). Gamma-Band Frequency Analysis and Motor Development in Music-Trained Children: A Cross-Sectional Study. *Journal of Motor Behavior*, *54*(2), 203–211. https://doi.org/10.1080/00222895.2021.1940820

Degé, F., & Schwarzer, G. (2011). The Effect of a Music Program on Phonological Awareness in Preschoolers. *Frontiers in Psychology*, *2*. https://doi.org/10.3389/fpsyg.2011.00124

Dhakal, A., & Bobrin, B. D. (2025). Cognitive Deficits. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK559052/

Dittinger, E., Chobert, J., Ziegler, J. C., & Besson, M. (2017). Fast Brain Plasticity during Word Learning in Musically-Trained Children. *Frontiers in Human Neuroscience*, *11*, 233. https://doi.org/10.3389/fnhum.2017.00233

Fasano, M. C., Semeraro, C., Cassibba, R., Kringelbach, M. L., Monacis, L., de Palo, V., Vuust, P., & Brattico, E. (2019). Short-Term Orchestral Music Training Modulates Hyperactivity and Inhibitory Control in School-Age Children: A Longitudinal Behavioural Study. *Frontiers in Psychology*, *10*, 750. https://doi.org/10.3389/fpsyg.2019.00750

Ferreri, L., Mas-Herrero, E., Zatorre, R. J., Ripollés, P., Gomez-Andres, A., Alicart, H., Olivé, G., Marco-Pallarés, J., Antonijoan, R. M., Valle, M., Riba, J., & Rodriguez-Fornells, A. (2019). Dopamine modulates the reward experiences elicited by music. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(9), 3793–3798. https://doi.org/10.1073/pnas.1811878116

Flaugnacco, E., Lopez, L., Terribili, C., Montico, M., Zoia, S., & Schön, D. (2015). Music Training Increases Phonological Awareness and Reading Skills in Developmental Dyslexia: A Randomized Control Trial. *PLOS ONE*, *10*(9), e0138715. https://doi.org/10.1371/journal.pone.0138715

Gaser, C., & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *23*(27), 9240–9245. https://doi.org/10.1523/JNEUROSCI.23-27-09240.2003

Gencigör, M. C., & Akın, S. (2024). Developing Children's Motor Skills by Having Fun With Orff's Approach. *Perceptual and Motor Skills*, *131*(5), 1517–1530. https://doi.org/10.1177/00315125241272497

Harris, R., & de Jong, B. M. (2015). Differential parietal and temporal contributions to music perception in improvising and score-dependent musicians, an fMRI study. *Brain Research*, *1624*, 253–264. https://doi.org/10.1016/j.brainres.2015.06.050

Hennessy, S. L., Sachs, M. E., Ilari, B., & Habibi, A. (2019). Effects of Music Training on Inhibitory Control and Associated Neural Networks in School-Aged Children: A Longitudinal Study. *Frontiers in Neuroscience*, *13*, 1080. https://doi.org/10.3389/fnins.2019.01080

Herholz, S. C., & Zatorre, R. J. (2012). Musical Training as a Framework for Brain Plasticity: Behavior, Function, and Structure. *Neuron*, *76*(3), 486–502. https://doi.org/10.1016/j.neuron.2012.10.011

Hogan, T. P., Catts, H. W., & Little, T. D. (2005). The Relationship Between Phonological Awareness and Reading. *Language, Speech, and Hearing Services in Schools*, *36*(4), 285–293. https://doi.org/10.1044/0161-1461(2005/029)

Holmes, S., & Hallam, S. (2017). The impact of participation in music on learning mathematics. *London Review of Education*, *15*(3). https://doi.org/10.18546/LRE.15.3.07

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). Musical Training Shapes Structural Brain Development. *Journal of Neuroscience*, *29*(10), 3019–3025. https://doi.org/10.1523/JNEUROSCI.5118-08.2009

Kang, W., Hernández, S. P., Rahman, Md. S., Voigt, K., & Malvaso, A. (2022). Inhibitory Control Development: A Network Neuroscience Perspective. *Frontiers in Psychology*, *13*, 651547. https://doi.org/10.3389/fpsyg.2022.651547

Kausel, L., Zamorano, F., Billeke, P., Sutherland, M. E., Larrain-Valenzuela, J., Stecher, X., Schlaug, G., & Aboitiz, F. (2020). Neural Dynamics of Improved Bimodal Attention and Working Memory in Musically Trained Children. *Frontiers in Neuroscience*, *14*. https://doi.org/10.3389/fnins.2020.554731

Maldonado, K. A., & Alsayouri, K. (2025). Physiology, Brain. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK551718/

Menon, V. (2016). Memory and cognitive control circuits in mathematical cognition and learning. *Progress in Brain Research*, *227*, 159–186. https://doi.org/10.1016/bs.pbr.2016.04.026

Mix, K. S., & Cheng, Y.-L. (2012). Chapter 6 - The Relation Between Space and Math: Developmental and Educational Implications. In J. B. Benson (Ed.), *Advances in Child Development and Behavior* (Vol. 42, pp. 197–243). JAI. https://doi.org/10.1016/B978-0-12-394388-0.00006-X

Olszewska, A. M., Gaca, M., Droździel, D., Widlarz, A., Herman, A. M., & Marchewka, A. (2024). Understanding functional brain reorganization for naturalistic piano playing in novice pianists. *Journal of Neuroscience Research*, *102*(2), e25312. https://doi.org/10.1002/jnr.25312

Peters, L., & De Smedt, B. (2018). Arithmetic in the developing brain: A review of brain imaging studies. *Developmental Cognitive Neuroscience*, *30*, 265–279. https://doi.org/10.1016/j.dcn.2017.05.002

Popescu, T., Sader, E., Schaer, M., Thomas, A., Terhune, D. B., Dowker, A., Mars, R. B., & Cohen Kadosh, R. (2019). The brain-structural correlates of mathematical expertise. *Cortex*, *114*, 140–150. https://doi.org/10.1016/j.cortex.2018.10.009

Puderbaugh, M., & Emmady, P. D. (2025). Neuroplasticity. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK557811/

Raja, V., & and Bhalla, D. O. (2021). Impact of Carnatic music training on the mathematical ability of children. *Early Child Development and Care*, *191*(12), 1911–1921. https://doi.org/10.1080/03004430.2020.1832484

Rauscher, F. H., Shaw, G. L., & Ky, C. N. (1993). Music and spatial task performance. *Nature*, *365*(6447), 611–611. https://doi.org/10.1038/365611a0

Rauscher, F., Shaw ,Gordon, Levine ,Linda, Wright ,Eric, Dennis ,Wendy, & and Newcomb, R. (1997). Music training causes long-term enhancement of preschool children's spatial–temporal reasoning. *Neurological Research*, *19*(1), 2–8. https://doi.org/10.1080/01616412.1997.11740765

Ravasio, M. (2021). History of Western Philosophy of Music: Antiquity to 1800. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2021). Metaphysics Research Lab, Stanford

University. https://plato.stanford.edu/archives/fall2021/entries/hist-westphilmusic-to-1800/

Sakreida, K., Higuchi, S., Di Dio, C., Ziessler, M., Turgeon, M., Roberts, N., & Vogt, S. (2018). Cognitive Control Structures in the Imitation Learning of Spatial Sequences and Rhythms—An fMRI Study. *Cerebral Cortex*, *28*(3), 907–923. https://doi.org/10.1093/cercor/bhw414

Sarnthein, J., vonStein ,Astrid, Rappelsberger ,Peter, Petsche ,Hellmuth, Rauscher ,Frances, & and Shaw, G. (1997). Persistent patterns of brain activity: An EEG coherence study of the positive effect of music on spatial-temporal reasoning. *Neurological Research*, *19*(2), 107–116. https://doi.org/10.1080/01616412.1997.11740782

Schel, M. A., & Klingberg, T. (2017). Specialization of the Right Intraparietal Sulcus for Processing Mathematics During Development. *Cerebral Cortex (New York, N.Y.: 1991)*, *27*(9), 4436–4446. https://doi.org/10.1093/cercor/bhw246

Sharda, M., Tuerk, C., Chowdhury, R., Jamey, K., Foster, N., Custo-Blanch, M., Tan, M., Nadig, A., & Hyde, K. (2018). Music improves social communication and auditory–motor connectivity in children with autism. *Translational Psychiatry*, *8*(1), 1–13. https://doi.org/10.1038/s41398-018-0287-3

Slater, J., Skoe, E., Strait, D. L., O'Connell, S., Thompson, E., & Kraus, N. (2015). Music training improves speech-in-noise perception: Longitudinal evidence from a community-based music program. *Behavioural Brain Research*, *291*, 244–252. https://doi.org/10.1016/j.bbr.2015.05.026

Stewart, L., Henson, R., Kampe, K., Walsh, V., Turner, R., & Frith, U. (2003). Becoming a pianist. An fMRI study of musical literacy acquisition. *Annals of the New York Academy of Sciences*, *999*, 204–208. https://doi.org/10.1196/annals.1284.030

Tavares, V. D. de O., Rossell, S. L., Schuch, F. B., Herring, M., Menezes de Sousa, G., Galvão-Coelho, N. L., & Hallgren, M. (2023). Effects of exercise on cognitive functioning in adults with serious mental illness: A meta analytic review. *Psychiatry Research*, *321*, 115081. https://doi.org/10.1016/j.psychres.2023.115081

Toader, C., Tataru, C. P., Florian, I.-A., Covache-Busuioc, R.-A., Bratu, B.-G., Glavan, L. A., Bordeianu, A., Dumitrascu, D.-I., & Ciurea, A. V. (2023). Cognitive Crescendo: How Music Shapes the Brain's Structure and Function. *Brain Sciences*, *13*(10), 1390. https://doi.org/10.3390/brainsci13101390

Wang, J., Joanisse, M. F., & Booth, J. R. (2023). Learning to Read Strengthens Functional Connectivity Between the Ventral Occipitotemporal Cortex and the Superior Temporal Gyrus During an Auditory Phonological Awareness Task. *Journal of Speech, Language, and Hearing Research: JSLHR*, *66*(11), 4532–4546. https://doi.org/10.1044/2023_JSLHR-23-00337

Wang, J., Pines, J., Joanisse, M., & Booth, J. R. (2021). Reciprocal relations between reading skill and the neural basis of phonological awareness in 7- to 9-year-old children. *NeuroImage*, *236*, 118083. https://doi.org/10.1016/j.neuroimage.2021.118083

What's the Function of the Corpus Callosum? (n.d.). Cleveland Clinic. Retrieved February 23, 2025, from https://my.clevelandclinic.org/health/body/corpus-