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The impact of music training on executive functioning in children and adolescents: a narrative review

Abstract

Background: Executive functions (EFs) are higher-order cognitive processes that support goal-directed behavior, self-regulation, learning, and adaptive functioning. Because childhood and adolescence represent critical periods of executive-function development, there is increasing interest in interventions capable of strengthening these cognitive abilities. Music training has emerged as a promising candidate because it simultaneously engages auditory, motor, attentional, memory, and emotional systems.

Objective: To review current evidence regarding the impact of music training on executive functioning in children and adolescents and to examine underlying neurobiological mechanisms, educational implications, and potential clinical applications.

Methods: A narrative review of studies examining music training and executive-function outcomes in pediatric populations was conducted. Evidence from observational studies, longitudinal investigations, randomized controlled trials, neuroimaging studies, systematic reviews, and meta-analyses were synthesized.

Results: Music training appears to be associated with improvements in the core executive domains of working memory, inhibitory control, and cognitive flexibility. Neuroimaging studies demonstrate structural and functional adaptations within prefrontal, auditory, motor, and cerebellar networks that support executive functioning. Longitudinal studies and randomized controlled trials provide evidence suggesting that music training may contribute to executive-function development beyond normal maturation. Additional benefits have been reported in academic achievement, emotional regulation, and social functioning. Emerging evidence also supports the use of music-based interventions in children with neurodevelopmental disorders, including attention-deficit/hyperactivity disorder and autism spectrum disorder.

Conclusion: Current evidence supports a positive association between music training and executive functioning in children and adolescents. Although methodological limitations prevent definitive causal conclusions, findings suggest that music education may represent a valuable strategy for promoting cognitive development and enhancing psychosocial outcomes during childhood and adolescence.

Keywords: music training, executive function (EF), working memory (WM), inhibitory control, cognitive flexibility, neuroplasticity, children, adolescents, cognition

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Introduction

Executive function development during childhood and adolescence

Executive functions (EFs) represent a collection of top-down, interrelated cognitive processes—primarily working memory, inhibitory control, and cognitive flexibility—that enable individuals to regulate thoughts, emotions, and behavior in a goal-directed manner.[1] These foundational processes are vital for daily functioning, concentration, and adaptive decision-making, serving as the architecture for higher-order abilities such as planning, organization, reasoning, problem-solving, and self-monitoring.

Inhibitory control, which comprises both behavioral inhibition and interference control, is the capacity to resist environmental distractions, suppress impulsive actions, and exercise self-discipline. This mechanism allows individuals to select focus selectively and choose actions based on long-term goals rather than immediate stimuli. Working memory (WM) involves the temporary maintenance and active manipulation of information. WM manifests in two subsystems: verbal and non-verbal (visual-spatial). Distinct from simple short-term passive recall, working memory requires complex neural subsystems to manipulate data dynamically, enabling mental arithmetic, retrospective retrieval for present choices, and language comprehension. Inhibitory control and working memory operate synergistically to scaffold the third core domain: cognitive flexibility. Cognitive flexibility is the capacity to think adaptively, switch perspectives, and deploy divergent thinking when conditions change. Shifting between perspectives requires an individual to temporarily inhibit one viewpoint while holding another in active memory, highlighting the structural interdependence of these core domains.

While executive functioning begins to manifest during infancy, it undergoes its most dramatic expansion during childhood and adolescence. This developmental trajectory is driven by neurological processes including synaptic pruning, myelination, and enhanced neural efficiency, which correlate with the functional maturation of the prefrontal cortex and its extensive networks connecting parietal, temporal, subcortical, and cerebellar regions. Because these networks

develop across an extended developmental window, they are highly susceptible to environmental influences, experiential learning, and structured interventions.

Humans are not born with fully realized EFs; instead, these capacities are cultivated through dynamic interactions and experiential learning. Early childhood interactions with caregivers form the baseline, while interactive, creative play in early education further accelerates development. Music training represents a uniquely structured environment for this optimization. For instance, in children aged 5 to 7 years, learning to sing in rounds or execute complex, syncopated rhythms repeatedly challenges behavioral inhibition and working memory. As children transition into instrumental training (typically from age 7 onward), the cognitive load scales substantially. Playing an instrument forces simultaneous engagement of working memory (retaining notation and musical structures) and inhibitory control (suppressing erroneous motor responses and regulating posture). When executing complex compositions, young musicians must balance rigorous structural constraints with artistic choices, creating a high-demand environment for cognitive flexibility.

Given that robust executive skills strongly predict academic achievement, social competence, emotional regulation, and long-term occupational success, assessing and tracking EF trajectories in pediatric populations remains a clinical priority.[2] Researchers utilize performance-based behavioral tasks, computerized cognitive batteries, neuroimaging techniques, and standardized informant-rating scales to map these skills, though debates regarding optimal cross-domain measurement metrics persist. Conversely, executive deficits are recognized as central features in several neurodevelopmental and psychological conditions, including attention-deficit/hyperactivity disorder (ADHD), autism spectrum disorder (ASD), and learning disabilities. Consequently, identifying scalable interventions capable of improving EF trajectories has become a vital objective.[3] Approaches such as physical activity, mindfulness training, bilingualism, and computerized cognitive training have all been evaluated.[4] Among these, music education remains uniquely compelling because it demands simultaneous, cross-modal cognitive processing while maintaining high intrinsic motivation and emotional engagement.[5]

Discussion

Music training as an enriched developmental experience

Musical practice stands as one of the most cognitively demanding activities a child can undertake, requiring milliseconds-level coordination among auditory, motor, visual, attentional, and emotional networks. Repeated engagement of these distributed systems leverages neuroplasticity—the central nervous system's capacity to structurally and functionally reorganize in response to environmental demands.[6] By forcing the cognitive architecture to process real-time sensory inputs and execute precise motor outputs, music training serves as a profound environmental enrichment experience that drives adaptive neural modifications.

Neurobiological foundations of music training and executive function

The link between musical training and executive functioning is increasingly supported by structural and functional neuroimaging evidence. Magnetic resonance imaging (MRI) studies reveal greater cortical thickness and gray matter volume in musicians relative to non-musicians within the prefrontal cortex, auditory cortex, supplementary motor areas, cerebellum, and the corpus callosum. These areas govern executive control, working memory, attentional shifting, and bimanual motor planning.

Importantly, longitudinal investigations demonstrate that relatively short periods of structured instrumental instruction can produce measurable alterations in pediatric neural connectivity, suggesting that music training accelerates the functional maturation of executive networks.[7] Children engaged in sustained music education display enhanced development of auditory tracts and more robust functional integration between sensory cortices and the frontoparietal networks that modulate cognitive control compared to their non-musical peers.[8]

Music training and working memory

Beyond broad cognitive metrics like intelligence quotient (IQ), music training engages a highly structured auditory processing framework that maps directly onto memory architectures, improving attention, focus, and verbal retrieval. This cognitive scaffolding underpins higher academic achievement and offers valuable therapeutic utility in phonetic and speech-language rehabilitation. The downstream neurological improvements observed with consistent musical practice yield heightened focus in educational environments, presenting a compelling argument for embedding structured music instruction directly into core school curricula from an early age rather than treating it as an optional extracurricular activity.

During a musical performance, working memory is continuously taxed. Musicians must encode, retrieve, and manipulate data regarding rhythm, pitch, dynamics, and articulation, while simultaneously anticipating upcoming measures, monitoring real-time auditory feedback, and correcting physical execution.

Numerous empirical studies confirm superior working memory performance in musically trained cohorts relative to control groups.[9] Neuropsychological testing demonstrates performance advantages across both verbal and visuospatial working memory domains, indicating far-transfer effects that extend beyond music-specific skills. Longitudinal data verify that these differences are not merely an artifact of self-selection; children assigned to structured music programs over multi-year intervals show significantly greater linear gains in working memory capacity than peers assigned to alternative active control activities.[10] Meta-analytic reviews substantiate this positive association, noting that the magnitude of effect sizes correlates with training frequency, intensity, and overall duration.[11]

The primary mechanisms driving these working memory improvements include:

1) Continuous, deliberate exercise of auditory memory systems via the encoding, storage, and manipulation of complex sequential patterns.
2) The optimization of top-down attentional control, which protects working memory maintenance by filtering out environmental distractions.
3) The structural strengthening of white matter tracts within the frontoparietal networks that mediate working memory operations.

Music training and inhibitory control

Inhibitory control is essential for behavioral self-regulation, affective management, and academic engagement. Children with robust inhibitory control are better equipped to sustain selective attention, follow multi-step rules, and suppress emotional volatility.

Musical training places exceptional demands on these suppression systems. Performers must actively inhibit incorrect motor movements,

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maintain a steady internal tempo despite external distractions, and carefully control physical dynamics. This demand is magnified during ensemble or orchestral performance, where individuals must suppress the impulse to deviate from the group while monitoring competing acoustic streams. Studies using classical paradigms such as Stroop, Go/No-Go, and Flanker tasks show superior inhibitory performance in musically trained pediatric populations.[12] Neuroimaging data confirm that these behavioral advantages correspond to elevated activation efficiency within the prefrontal regions that mediate cognitive control.[13] Furthermore, recent randomized controlled trials (RCTs) provide causal evidence, showing marked post-intervention improvements in behavioral inhibition following structured musical training.

Music training and cognitive flexibility

Cognitive flexibility permits the adaptive shifting of focus and strategy in response to changing environmental rules or unexpected obstacles. This attribute is vital during the transitions of childhood and adolescence, where escalating academic loads and shifting peer dynamics require ongoing psychosocial adaptation. Cognitive flexibility is heavily linked with creative problem-solving and resilience, while deficits in this domain are implicated in conditions such as ASD, ADHD, and obsessive-compulsive disorder.

Music environments provide an ideal arena for exercising cognitive flexibility. Musicians must continuously adapt to shifting tempos, meters, keys, and expressive styles. Performance necessitates rapid attention-switching between reading visual notation, executing motor sequences, monitoring acoustic feedback, and adjusting to co-performers. Improvisational activities further challenge this system, requiring the real-time generation of novel melodic sequences within strict stylistic, harmonic, and rhythmic boundaries.[14] This process requires rapid evaluation of alternative choices and fluid adaptation, making improvisation an exceptionally potent vehicle for driving cognitive flexibility.

Musically trained children demonstrate clear performance advantages on task-switching tests, the Wisconsin Card Sorting Test, and the Trail Making Test.[9] Neuroimaging indicates that these benefits are mediated by enhanced functional connectivity between the frontal and parietal regions responsible for attentional shifting.[15] This cross-domain flexibility is highly valuable in modern educational settings that prioritize innovation and interdisciplinary problem-solving, enabling students to transfer abstract concepts across domains.[16]. However, future investigations must clarify whether specific instructional modalities (e.g., jazz improvisation versus classical ensemble training) elicit distinct patterns of cognitive adaptation.

Core domains and empirical evidence

Table 1 Core executive functions and potential effects of music training

Executive function	Definition	Musical demands involved	Reported effects
Working Memory	Temporary storage and manipulation of active information.	Reading notation, memorizing melodies, anticipating musical phrases.	Enhanced verbal and visuospatial working memory capacity.
Inhibitory Control	Suppression of automatic, inappropriate, or impulsive responses.	Precise rhythmic timing, error suppression, maintaining collective tempo.	Improved selective attention, focus, and behavioral self-regulation.
Cognitive Flexibility	Capacity to shift perspective, rules, or problem-solving strategies.	Real-time accompaniment adjustments, musical improvisation, task-switching.	Heightened task-switching efficiency and adaptive thinking.
Planning & Organization	Goal-directed sequencing of complex actions.	Managing practice schedules, structure mapping, performance preparation.	Improved structural organization and scholastic study habits.
Error Monitoring	Detection, evaluation, and correction of mistakes.	Real-time adjustment of pitch, intonation, and physical articulation.	Heightened self-monitoring accuracy and performance precision.

Table 2 Representative studies examining music training and executive function

Study	Design	Participants	Key findings
Habibi et al.,[8]	Longitudinal Cohort	Elementary school children	Music training was associated with accelerated structural brain development and parallel improvements in EF metrics.
Jaschke et al.,[7]	Longitudinal School-Based	Primary school children	Structured music education led to significant improvements in planning, behavioral inhibition, and cognitive flexibility.
Moreno et al.,[13]	Randomized Controlled Trial	School-aged children	Short-term computerized music training elicited significant improvements in prefrontal executive control networks.
Degé & Frischen[10]	Experimental Review	Multiple pediatric cohorts	Documented consistent, broad-spectrum benefits across multiple core executive functioning domains.
Shen et al.,[11]	Systematic Review & Meta-Analysis	Children and adolescents	Confirmed small-to-moderate positive summary effect sizes of music training on comprehensive EF outcomes.

Translational and clinical applications

Academic achievement and educational outcomes

The relationship between music education and academic performance remains a core focus of educational policy. EFs are robust predictors of scholastic success, directly governing reading comprehension, mathematical computation, written syntax, and classroom behavioral adaptation. By optimizing these underlying executive capacities, music training may act as an upstream catalyst for broader academic achievement.

Evidence points to robust positive correlations between music training and language competencies. Learning music sharpens auditory

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frequency discrimination, temporal processing, and phonological awareness—the foundational building blocks of literacy.[17] Musically trained children frequently outperform non-musician controls on standardized metrics of phonemic decoding, vocabulary acquisition, and reading comprehension.[18] Neuroimaging underscores this connection, demonstrating overlapping neural substrates for language and music processing within frontal and temporal cortices.[19] These shared networks offer a compelling neurological explanation for the observed far-transfer effects from musical literacy to linguistic proficiency.

Similarly, mathematical achievement is closely tied to music education. The perception of rhythm requires processing temporal patterns, ratio-based proportions, and sequential arrangements—skills that share conceptual foundations with mathematical operations.[20] Longitudinal tracking shows higher mathematics marks among cohorts enrolled in sustained instrumental programs.[7] While effect sizes fluctuate across studies, concurrent gains in working memory, sustained attention, and spatial pattern recognition likely drive these math-related benefits.

Beyond subject-specific metrics, musical participation correlates with improved school engagement, lower truancy rates, higher intrinsic motivation, and elevated secondary school graduation rates.[21] Enrolled students report a stronger sense of institutional belonging and social cohesion. These psychosocial variables bolster academic outcomes by cultivating resilience, self-discipline, and a long-term commitment to learning. However, interpreting these findings requires methodological caution, as confounding variables such as socioeconomic status (SES), parental education, and baseline intelligence can influence both enrollment in music lessons and academic trajectories.[22] While randomized trials lend increasing support to a causal framework, identifying the independent variance explained by music training remains an ongoing research objective.

Social-emotional development

Executive functions also modulate emotional regulation and social competence. Music education provides unique venues for cultivating these capacities through both solitary practice and collective performance. Ensemble, choir, or orchestral participation demands intense cooperation, non-verbal communication, mutual empathy, and shared intentionality, fostering prosocial behavioral traits critical for healthy social development.[23]

Furthermore, music serves as an effective medium for affective processing and emotional regulation. Children and adolescents routinely utilize music to navigate emotional distress, mitigate stress, and externalize complex internal states that resist verbal expression. Musical engagement activates subcortical and cortical networks involved in reward processing, emotional regulation, and social bonding.[24] Recurrent engagement in emotionally rich musical activities can strengthen self-awareness and affective resilience.[25]

Studies note heightened self-esteem, self-efficacy, and psychological well-being in children enrolled in music programs, often driven by milestone achievements, mastery experiences, and positive peer group identification. Moreover, group music-making requires continuous perspective-taking, compelling students to listen actively and adjust their actions relative to the group. This dynamic is especially valuable during adolescence—a phase marked by intensive identity construction, heightened social vulnerability, and rising affective demands. Music collectives offer a safe, validating framework that helps adolescents build self-regulation skills, establish stable peer alliances, and form a positive sense of self.[26]

Music-based interventions in neurodevelopmental disorders

Emerging clinical evidence highlights the therapeutic potential of music-based interventions for pediatric neurodevelopmental disorders characterized by executive dysfunction. Because music inherently recruits attentional networks, reward pathways, and memory systems, it functions as a highly motivating therapeutic modality in pediatric neurorehabilitation and developmental medicine.

In ADHD, where deficits in inhibitory control and sustained attention represent core diagnostic features, preliminary clinical studies suggest that structured music instruction enhances attentional control, decreases behavioral impulsivity, and extends task persistence. Rhythmic-auditory entrainment interventions appear highly promising, as they directly engage the neural timing networks that modulate attentional deployment and motor control.[27,28]

Children with autism spectrum disorder (ASD) also show positive responses to music-based protocols, with data demonstrating gains in dyadic social communication, joint attention, emotional reciprocity, and functional adaptive behaviors following music therapy.[29,30] The predictable, structured, yet highly engaging architecture of music provides a non-threatening communicative bridge, facilitating social reciprocity while bypassing the anxieties frequently paired with direct verbal dialogue.

Additionally, music interventions show promise for children with developmental dyslexia and related learning differences, yielding improvements in auditory edge-detection, phonological processing, and reading speed.[31] While clinical trials show some heterogeneity in outcomes, the data suggest that music-based training serves as an excellent, non-pharmacological adjunct to standard educational and therapeutic regimens. It is highly accessible, scalable, and generally boasts excellent adherence rates among pediatric patients and families. Larger, multicenter randomized controlled trials are now required to standardize clinical protocols and evaluate long-term functional outcomes.

Conclusion

Executive functions are essential pillars guiding cognitive, scholastic, and social-emotional development throughout childhood and adolescence. The current literature indicates that music training operates as a powerful, multi-modal intervention capable of optimizing these vital cognitive systems. By forcing simultaneous compliance across attentional, mnemonic, motor, and emotional domains, music training offers a uniquely enriched environment for brain development.

Data spanning developmental psychology, cognitive neuroscience, education, and clinical science consistently demonstrate that music training correlates with functional gains in working memory, inhibitory control, and cognitive flexibility. These behavioral shifts are mirrored by structural and functional adaptations within the frontoparietal and subcortical networks that govern executive control. Furthermore, these adaptations yield broad far-transfer benefits, including enhanced academic outcomes, social-emotional maturity, self-efficacy, and psychological resilience.

While certain methodological constraints persist—requiring further work to map explicit causal pathways—the collective weight of evidence shows that music education is far more than a simple aesthetic elective. Instead, it represents a potent, evidence-based strategy for fostering healthy cognitive development and optimizing life trajectories for children and adolescents. As educational institutions increasingly shift toward whole-child developmental

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models, structured music education should be prioritized as an essential pillar of standard academic curricula. For educators, clinicians, and policymakers alike, these data underscore the clear need to expand and protect equitable access to high-quality music training for all youth.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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