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"Playing" it Safe: The Effects of Music Training on Substance Use Disorder Vulnerabilities in Children with ADHD

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AUTHOR BIOGRAPHY

Rachel Ding is a member of the Class of 2026 at St. Mark's School in Massachusetts and the Class of 2030 at Duke University, where she plans to study Psychology, Education, Child Policy, and Asian American Studies. Her research focuses on ADHD in children, particularly aiming to improve awareness and support within Asian American communities.

ABSTRACT

Attention Deficit Hyperactivity Disorder (ADHD) is a common neurodevelopmental disorder that poses significant risk for Substance Use Disorder (SUD). Deficits in inhibitory control and reward regulation are the underlying mechanisms that predispose children with ADHD to developing SUD. Music training (MT), defined as formal instruction in playing an instrument, may help improve inhibitory control and related executive functions. This study examines how and to what extent MT for children with ADHD affects their risk for SUD through a transdisciplinary lens, drawing from literature in developmental psychology, neurobiology, music education, and addiction studies. MT, particularly orchestral training, is found to enhance inhibitory skills. However, MT may not significantly improve delayed gratification. Moreover, there is insufficient evidence on MT's impact on these two abilities in the target demographic, that is, children with ADHD. While MT may indirectly protect against SUD by strengthening inhibitory control, further research is needed to clearly and directly establish its impact on incident SUD.

Keywords: *Attention Deficit Hyperactivity Disorder, Substance Use Disorder, Music Training, Executive Functioning, Inhibitory Control, Reward Regulation, Delay Discounting, Child Development*

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INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common neurodevelopmental disorders in childhood and adolescence (Salari et al., 2023). In 2022, approximately one in nine children had ever been diagnosed with ADHD (11.4%, 7.1 million) in the United States (Danielson et al., 2024). ADHD is a neurodevelopmental condition characterized by persistent patterns of inattention, hyperactivity, and impulsivity (American Psychiatric Association [APA], 2022). ADHD symptoms must appear before age 12 to warrant a diagnosis (APA, 2022), suggesting that childhood is a critical period for recognizing and treating ADHD as well as protecting against the development of disorders for which individuals with ADHD are at increased risk (Antoniou et al., 2021).

One such condition is substance use disorder (SUD) (Mustonen et al., 2023). The APA (2022) defines SUD as the continued use of psychoactive substances despite significant cognitive, behavioral, and physiological consequences. SUD ranges widely in severity, from a "mild form to a severe state of chronically relapsing, compulsive pattern of drug taking" (APA, 2022, p. 543). SUD encompasses nine classes of substances (alcohol, cannabis, hallucinogens, inhalants, opioids, sedatives/hypnotics/anxiolytics, stimulants, tobacco, and other/unknown; APA, 2022). However, common to all these variants is the addictive potential of the substances involved (Volkow & Blanco, 2023), which poses increased risk for individuals with impaired reward-related decision making and inhibition (Ceceli et al., 2021; File et al., 2022).

Dysfunctions in inhibitory and reward systems in children with ADHD are the primary risk factors for the development of SUD during adolescence and adulthood (Barbuti et al., 2023). A promising intervention that may accelerate the development of inhibitory control (Anand, 2022) and delayed gratification is music training (MT) (Hennessy et al., 2019). MT can be defined as receiving formal instruction in playing an instrument (Anand, 2022).

BACKGROUND

Children with ADHD are at significantly greater risk for developing SUD than children without ADHD (Chadi et al., 2020). Individuals with ADHD are not only two to three times more likely to develop a SUD (Schellekens et al., 2020; Lee et al., 2011) but also significantly more likely to develop a severe form of it (Pallucchini et al., 2021). For individuals with ADHD, SUD is associated with an earlier age of onset, increased polydrug abuse, suicidal behaviors, relapse rate, and hospitalizations, and lower adherence to treatment (Barbuti et al., 2023). Substance use exacerbates coexisting ADHD, which is known to increase the likelihood of substance and consequently the progression to SUD (Chadi et al., 2020). Both the implications and prevalence of SUD are particularly concerning for individuals with ADHD.

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Individuals with ADHD and SUD demonstrate low inhibitory control (Neo et al., 2024). Inhibitory control is the ability to suppress "prepotent, ongoing, or impulsive responses" (Paraskevopoulou et al., 2022, p. 2). Deficient inhibitory control is a pathophysiological feature of ADHD, particularly among children (Kofler et al., 2024). Impaired executive functioning, such as impulse control (Liu et al., 2024), may predispose individuals with ADHD to trying substances and developing addiction (Perugi et al., 2018).

ADHD and SUD also share the phenotypic characteristic of increased reward seeking (Paraskevopoulou et al., 2022). The type of rewards individuals with ADHD and SUD tend to prefer are "smaller sooner" over "larger later" rewards (Bitsakou et al., 2009; Scheres et al., 2024). To a certain extent, this tendency can be explained by the delay aversion theory, which proposes that individuals with ADHD find delays particularly aversive (Broulidakis et al., 2022). Due to their difficulties in delaying or modulating reward response, individuals with ADHD may have a strong tendency to develop multiple addictive behaviors (Perugi et al., 2018).

Research on MT offers encouraging evidence of its potential protective properties. MT may improve children's executive functioning, especially inhibition control (Jamey et al., 2024). Indeed orchestral MT may facilitate the development of inhibitory control by modulating self-reported hyperactivity levels (Fasano et al., 2019). For children with ADHD, learning an instrument improves their attention, concentration, impulse control, motivation, and memory (Wilde, 2019).

THE PROBLEM

While numerous studies have focused on the relationship between ADHD and SUD (Barbuti et al., 2023; François A. M. et al., 2023; Schellekens et al., 2020; Srichawla et al., 2022), ADHD and MT (Anand, 2022; Luo & Zhang, 2025; Mastnak, 2022; Raz, 2024; Tedesco, 2023; Wilde, 2019), and SUD and MT (Ahrends, 2017), few have examined the intersection between all three, in the context of childhood, from a transdisciplinary perspective. Currently, there are considerable challenges in the treatment of comorbid ADHD and SUD (Barbuti et al., 2023). Therefore, it becomes all the more important to focus on preventing SUD onset in individuals with ADHD.

RESEARCH QUESTION

To address the perceived gap in the literature, this study seeks to answer the following question: How and to what extent does MT for children with ADHD impact their likelihood of developing SUD?

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LITERATURE REVIEW

To address the research question, "How and to what extent can MT for children with ADHD impact their likelihood of developing SUD?", the literature review is organized into five sections: the correlation between ADHD and SUD, the two underlying mechanisms linking ADHD to SUD, and how MT impacts these two risk factors.

LITERATURE GENRES

This literature review draws primarily from peer-reviewed journal articles, dissertations, and theses published within the last ten years.

ADHD as a Risk Factor for SUD

Barbuti et al. (2023) recently reviewed the treatment of comorbid ADHD and SUD, referencing a meta-analysis by Groenman et al. (2017) on the prospective risk posed by child psychiatric disorders for subsequent substance-related disorders. The meta-analysis included 37 studies published in English from 1986 to May 2016. The total sample size was 762,187 participants, 22,029 of whom had ADHD. Across the 37 studies, the mean age at baseline was 12.85 years and at follow-up was 21.98 years. Overall, individuals with childhood ADHD were found to be over two and a half times more likely to develop SUDs. For substance-specific disorders, children with ADHD were more than twice as likely to develop problematic alcohol use; two and a half times more likely to develop nicotine-related issues, such as dependence; and approximately 1.5 times of developing drug-related disorders. Meta-regression analysis revealed that studies that included younger participants at baseline showed significantly larger effect sizes for ADHD and overall addiction, as well as alcohol-related disorders.

Mustonen et al. (2023) conducted a general population-based birth cohort study to examine the association between adolescent ADHD and ODD symptoms and clinical SUD diagnosis until age 33. The study included 6,278 individuals: 188 had both ADHD and ODD and 355 had only ADHD at age 16. ADHD/ODD case status was determined by parent-ratings of ADHD. Self-reports of adolescent substance use revealed that individuals with ADHD were more likely to report lifetime substance use (11.4% for cannabis vs. 4.9%; 8.2% for other substances vs. 3.0%) and frequent alcohol intoxication (31.2% vs. 16.9%) compared to those without. Furthermore, individuals with adolescent ADHD had a significantly higher incidence of SUD during follow-up (7.4% vs. 2.0% in the non-ADHD group). Even after adjusting for potential confounding factors (e.g., ODD), adolescent ADHD case status remained significantly associated with incident SUD. Sensitivity analyses indicated individuals with levels of ADHD-like characteristics at both extremes (either very low or high) had the

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greatest risk. Mustonen et al.' (2023) findings support the positive correlation between ADHD and SUD established by past clinical, register-based, twin, and cohort studies.

Despite the frequent comorbidity of ADHD and SUD, ADHD serves as a risk factor for SUD and not the reverse. ADHD, particularly before adulthood, serves as a significant risk factor for developing SUD. This predisposition can be traced back to childhood. Indeed, children may be over two times as likely to develop a SUD as children without ADHD (Groenman et al., 2017). Furthermore, a younger age of onset for ADHD may lead to more severe addiction (Groenman et al., 2017). Similarly, individuals with ADHD during adolescence had an over three times higher incidence of SUD in adulthood compared to those without (Mustonen et al., 2023). There is strong support for this association as these studies included robust sample sizes and controlled for potentially confounding and moderating variables.

Inhibitory Control Underlying ADHD and SUD

Cavicchioli et al. (2022) examined deficient self-regulation as a mediator between childhood ADHD and SUD in adulthood. Their study included 204 treatment-seeking adults. Participants filled out self-report questionnaires to assess the severity of their retrospective childhood ADHD symptoms, the severity of their SUD in the past 12 months, and three subsets of their self-regulation. Childhood ADHD was measured using the Wender Utah Rating Scale, and SUD was measured using the Shorter PROMIS Questionnaire. Behavioral disinhibition, attention regulation, and emotion regulation were measured on the Barratt Impulsiveness Scale, the Mindful Attention Awareness Scale, and the Difficulties in Emotion Regulation Scale, respectively. The severity of childhood ADHD symptoms significantly predicted the severity of SUDs in adulthood, suggesting that childhood ADHD is a risk factor for adult SUDs regardless of whether ADHD persists into adulthood. Deficits in self-regulation were found to mediate this association. Childhood ADHD symptoms significantly predicted higher levels of behavioral disinhibition, which was found to have a significant indirect effect on SUD severity.

Increased reward-seeking is a phenotypic characteristic shared by both ADHD and SUD (Paraskevopoulou et al., 2022). Paraskevopoulou et al. (2022) investigated the impact of substance misuse (SM) on inhibitory control in adolescents and young adults with ADHD. The study comprised 99 participants, evenly spread across three groups: ADHD-only, ADHD + SM, and control. They collected behavioral and functional magnetic resonance imaging (fMRI) data while participants completed a standard stop-signal task. Paraskevopoulou et al. (2022) found that patients with ADHD, whether they misused substances or not, exhibited deficits in neural networks related to inhibitory control (specifically frontostriatal and frontoparietal networks) compared to those without ADHD. Contrary to their hypothesis, substance use was not found to exacerbate response inhibition.

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Childhood symptoms (i.e., difficulties with behavioral, attentional, and emotional self-regulation) may predispose individuals with ADHD to developing SUD, even if the symptoms themselves may diminish in adulthood (Cavicchioli et al., 2022). Specifically, the severity of childhood ADHD symptoms may predict the severity of subsequent SUD (Cavicchioli et al., 2022). This finding may suggest that childhood may be a particularly sensitive period for learning self-regulatory skills to protect against later SUD (Cavicchioli et al., 2022). Given that substance may not exacerbate response disinhibition (Paraskevopoulou et al., 2021), inhibitory control deficits likely stem from ADHD rather than from substance use. These deficits associated with ADHD may precede and potentially increase vulnerability to SUD.

Reward Dysregulation Underlying ADHD and SUD

Scheres et al. (2024) reviewed delay discounting as an underlying mechanism between both ADHD and SUD. They proposed that delay discounting may be a shared "intermediate phenotype" between these commonly comorbid conditions and moderate their longitudinal relationship. Additionally, Scheres et al. (2024) highlighted that in early childhood, ADHD is closely related to relatively steep delay discounting, which increases their risk for developing SUD. After the onset of SUD, drug use and heightened delay discounting mutually reinforce one another.

According to Marx et al. (2021), individuals with ADHD tend to prefer "smaller sooner" over "larger later" rewards. Marx et al. (2021) conducted a meta-analysis investigating impulsive decision-making in individuals with ADHD. They compared studies that used either the Simple Choice Paradigm (SCP) or the Temporal Discounting Paradigm (TDP). The meta-analysis included findings from 37 studies with 3,763 participants: 2,666 in the SCP and 1,097 in the TDP analyses. Both paradigms showed small-to-medium effect sizes. Overall, participants with ADHD choose small, immediate over large, delayed rewards more often than controls. In the SCP specifically, participants with ADHD were nearly twice as likely to choose the immediate reward/shorter delay compared to those without. However, when both the ADHD and control groups were offered real rewards in the SCP, the difference between impulsive decision-making was nearly halved. Marx et al. (2021) suggest that this finding aligns with the delay aversion theory.

The literature points to delay discounting as a mediator between childhood ADHD and later SUD. Children with ADHD often exhibit relatively steep delay, meaning they tend to prefer smaller, immediate over larger, delayed rewards (Marx, 2021), which may increase their risk for developing SUD (Scheres et al., 2024). According to Scheres et al. (2024), early protection against SUD is critical because once underway, it worsens impulsive, reward-related decision making in children with ADHD.

Music Training Impact on Inhibitory Control

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Playing in an orchestra requires "the discipline to sit patiently in silence for the entire execution of a piece waiting for your turn" (Fasano et al., 2019, p.2). Fasano et al. (2019) studied how a three-month-long orchestral MT program, called Music 'n' Play, would impact hyperactivity and inhibitory control in 55 Italian neurotypical children compared to 58 controls (aged 8 to 10 years). Fasano et al.' (2019) MT consisted of 10 weekly lessons. Each lesson lasted 2 hours and 15 minutes: 45 minutes of sectional rehearsals and 1.5 hours of playing with the full orchestra. The Walk-No Walk Test (Ranette) assessed selective and sustained attention and inhibitory control. A shortened version of the Matching Figures Test (MF-14) was used to measure impulsivity. Self-reported and observed hyperactivity-impulsivity and inattention were measured using the SDAB and SDAI scales, respectively (Marzocchi et al., 2010). Participants were examined at the training's start and end. From pre- to post-test, the inhibitory control scores increased significantly in the music group and only slightly/non-significantly for the controls. Additionally, the self-reported hyperactivity-impulsivity of the controls increased significantly while that of the music group did not significantly change.

On the contrary, Hogan et al. (2023) report that short-term orchestral MT may not improve young children's executive functioning. They conducted an experimental, longitudinal, and randomized controlled trial on whether participating in the Music 'n' Play program would improve three core components of executive functioning: working memory, inhibition, and cognitive flexibility. The study followed 146 rising first graders (mean age of 6.2 years) over two years: 91 received orchestral MT while 55 received general music education. Each week, the 91 treatment students received 140 to 495 minutes of orchestral training and the 55 controls received ~45 minutes of non-instrumental music instruction. The Flanker/Reverse Flanker task assessed all three core areas of executive functioning. Hogan et al. (2023) found that intensive orchestral MT compared to general music education did not cause significant gains in executive functioning. However, because the study never examined what would happen without MT, they could not conclude that it has no effect on executive functioning. Hogan et al. (2023) acknowledged that students practiced inhibitory control when they resisted the urge to play their instrument when it was not their turn. However, this skill did not translate to performance on the nonmusical tests as both groups' scores increased over time. This finding led Hogan et al. (2023, p.12) to conclude that executive functions cultivated by MT "remain specific to the context in which they were trained."

MT improves children's executive functioning, particularly inhibitory control, more than other activities (e.g., sports, visual arts, drama; Jamey et al., 2024). Jamey et al. (2024) systematically reviewed and meta-analyzed MT's impact on children's inhibitory control. The meta-analysis included 22 longitudinal studies and 1734 neurotypical children aged 3 to 11. When considering all 22 longitudinal studies, MT had a small-to-moderate effect size ($g = 0.31$). However, in the 8 Randomized Control Trials, Jamey et al. (2024) highlighted that MT training had a significant overall moderate-to-large effect size ($g = 0.60$). Jamey et al. (2024) highlighted the effect size of MT in comparison to the median effect size of other educational interventions ($g = 0.40$) according to Hattie's (2009) analysis of over 800 meta-analyses. Additionally, the context of MT was a significant moderator ($p = .047$). Training had greater impacts in a specialized music facility (0.13 higher effect

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size) than at a school. Based on strong evidence for the causal relationship between MT and inhibitory control, Jamey et al. (2024) recommended incorporating MT in early education and clinical contexts to improve inhibitory control in conditions like ADHD.

Recently, Lu et al. (2025) conducted a systematic review and meta-analysis on the effects of MT on 3- to 6-year-olds' executive functions. They meta-analyzed 10 studies, nine of which assessed inhibitory control. The total sample size was 807 children: 449 in the MT group and 358 in the control group. MT involved singing, playing instruments, composing music, and practicing pitch and rhythm. These interventions spanned anywhere between 4 weeks and 8 months. Across these studies, participants received MT anywhere between once a week and every day of the week, for 20 minutes to 2 hours each session. Lu et al. (2025) found that MT significantly improved children's inhibitory control compared to controls. Furthermore, MT that occurred for ≥12 weeks, ≥3 times per week, and for 20–30 minutes per session led to significant improvements in inhibitory control compared to the controls (Lu et al., 2025).

In Raz's (2024) study on the long-term cognitive benefits of instrumental MT in young adults with ADHD, the musicians had better sustained attention and impulse control than the non-musicians. Raz (2024) recruited 94 young adults with an ADHD diagnosis: 48 experienced guitar or piano players (having practiced an instrument for an average of 10.7 years ± 4.71 years) and 46 controls (with no prior experience playing any instruments). The Switching Task evaluated participants' higher-level executive functions, specifically cognitive flexibility and attention-shifting. In this task, musicians had slower reaction times, which indicated their ability to delay impulsive, premature responses better. Furthermore, on the Continuous Performance Test, musicians made significantly fewer commission errors in low and high target frequency sections. Commission errors are incorrect responses to a non-target and indicate poor inhibitory control or impulsivity. Therefore, according to Raz (2024), long-term MT may lead to more controlled and less impulsive responses in young adults with ADHD.

Tedesco (2023) conducted a five-week quasi-experimental study on the effects of string-instrument lessons on the attentiveness, classroom behavioral performance, and musical achievement of ten third-grade students with ADHD. The class was held daily for 40 minutes. Lessons involved listening to "Twinkle, Twinkle Little Star," remembering the melody, playing the song, and learning variations. Pre-tests, weekly assessments, and post-tests of the "Inattention" and "Classroom Behavioral Performance" subscales of the Vanderbilt ADHD Diagnostic Teacher Rating Scale and a researcher-made musical achievement rubric were administered. There were no control groups. Over the five weeks, Tedesco (2023) observed significant improvements in student attentiveness. The mean inattentiveness score dropped from 2.66 ("very often" inattentive) at pre-test to 1.47 ("less often" inattentive) at post-test. Additionally, students' classroom behaviors and musical achievement significantly improved.

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MT is a promising intervention to cultivate inhibitory control in children (Fasano et al., 2019; Hogan et al., 2023; Jamey et al., 2024; Lu et al., 2025), young adults with ADHD (Raz, 2024), and children with ADHD (Mastnak, 2022; Tedesco, 2023). Fasano et al. (2019, p. 9) conclude that even a "short, but systematic and engaging orchestral training program" may facilitate the development of inhibitory control and reduce hyperactivity in children. In contrast, Hogan et al. (2023) found that intensive orchestral MT may not be more effective than standard music education at improving inhibition. Though inhibitory control may have improved in the context of orchestral rehearsals, it may not necessarily translate beyond it (Hogan et al., 2023). Similarly, Jamey et al. (2024) found that the MT's effectiveness on improving inhibitory control strongly depended on its context (e.g., specialized music institution vs. regular school, instructor quality, facilities/equipment availability). Nonetheless, Jamey et al. (2024) suggest that MT may cause significant improvements in inhibitory control, more so than many other standard activities. Furthermore, Lu et al. (2025) went so far as to outline a set of parameters that may significantly improve inhibitory control in children: total duration of ≥12 weeks, ≥3 meetings per week, 20-30-minute-long meetings. Meanwhile, for young adults with ADHD, long-term MT (for multiple years) may lead to more controlled and less impulsive responses (Raz, 2024). In children with ADHD, MT may improve impulse control, inattentiveness, and overall classroom behavioral performance (Tedesco, 2023).

Music Training Impact on Reward Regulation

Hennesey's (2019) longitudinal study found that music-trained children delayed small-immediate rewards for delayed-large rewards, earlier and more often than children without MT. This study followed 88 children (mean age 6.81 years) for four years. They were divided into the music, sports, or control group. Children in the music group participated in an El Sistema-inspired orchestral program that met for 6 to 7 hours a week. All participants were assessed at "baseline" and annually from "Year 1" through "Year 4." Inhibitory control was measured using a Delayed Gratification task (Years 3 and 4), the Flanker task (Years 2 through 4) and the Color-Word Stroop task performed outside (Years 1 and 3) and inside (Years 2 and 4) an fMRI scanner. In the Delayed Gratification task, children who received MT demonstrated an "accelerated ability to reject a small, immediate reward in favor of a delayed, large reward" compared to children who had not received any training (Hennesey, 2019, p. 10). While children in all three groups delayed large rewards more as they got older, those in the music group did so earlier and more often. Additionally, musically trained children were less likely to delay discount small rewards, whereas children in the sports and control groups were more likely to do so with age. These behavioral findings are further supported by neuroimages from the fMRI Color-Word Stroop task. By Year 2, musically trained children showed "significantly greater bilateral activation" in the pre-supplementary and supplementary motor cortex, anterior cingulate cortex, inferior frontal gyrus, and insula (cognitive control networks) compared to the control group (Hennesey, 2019, p. 1). Unexpectedly, these differences were not observed in Year 4. This finding led Hennesey (2019) speculate that children in the music group may have matured earlier than those in the control group, who did not "catch up" until Year 4. Alternatively, this finding

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may have been confounded by the prevalence of bilingualism among participants (100% in the music group, 86.67% in the sports group, 100% in the control group). Both bilinguals and musically trained individuals must learn to suppress irrelevant stimuli and may develop inhibitory control skills in doing so. Bilingualism may begin to enhance inhibitory skills in infants as young as 7 months old. Therefore, if bilingual participants had already developed strong inhibitory control at baseline, MT's impact on inhibitory control may be difficult to distinguish due to the "ceiling effect." As a result, MT may appear deceptively less effective in improving inhibitory control. However, because at least *some* differences between the MT and other groups were observed, Hennesey (2019, p. 13) suggests that MT and bilingualism "may have a small additive effect early in development."

Frischen et al. (2022) examined the impact of MT on hot executive functions, including delayed gratification, in young adults (Study 1) as well as in 9- to 12-year-olds (Study 2). Study 1's sample size comprised 136 undergraduate students (118 female) from a German university. Most students (90%) had taken private music lessons for an average of 7.51 years, and 74% had played regularly in a music group for an average of 7.4 years. At the time of this study, only 6% of students were still taking music lessons, and 19% played regularly in a music group. Study 2 had a sample size of 100 children: 75% had taken music lessons (average duration 3.46 years), and 84% were still taking them. The Delay of Gratification Test for Adults (DoG-A) measured participants' ability to delay rewards. The DoG-A involves four decision-making tasks with different types of rewards (hypothetical money, snack, real money/present, magazines). In Study 1, Frischen et al. (2022) found a small, significant correlation between MT and the "present" item of the DoG-A. Furthermore, regression analyses revealed that MT predicted delayed gratification, explaining 5% of the variance. Given that "learning a musical instrument requires a lot of self-discipline, focusing on long-term goals, and resisting temptations," Frischen et al. (2022, p. 565) found it reasonable that MT is associated with the ability to delay gratification. However, no correlation was found between children's ability to delay gratification and MT in Study 2. According to Frischen et al. (2022, p. 572), this may be because there is "no such relation," the ability to delay rewards "only becomes apparent after a considerable number of years of music training," and/or that the "hypothetical items from the test do not create an extremely good incentive."

In summary, MT may improve children's ability to delay rewards, which is closely related to inhibitory control and decision-making. On the one hand, musically trained children delayed large rewards earlier and more often than those without training (Hennessy, 2019). On the other hand, Frischen et al. (2022) found that MT had no significant impact on children's ability to delay gratification. Nonetheless, Frischen et al. (2022) found a slight correlation in adult participants, in which the more MT adult participants received, the more likely they were to choose the delayed reward. Additionally, starting MT early may be associated with less risky decision-making, even though MT in and of itself may not improve affective decision-making (Frischen et al., 2022). Likewise, in the early stages of child development, both MT and bilingualism may individually help to develop inhibitory control and may also have some combined benefits (Hennessy, 2019).

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METHODOLOGY

A transdisciplinary literature review was conducted on the intersection of ADHD, SUD, and MT across fields of developmental psychology, neurobiology, music education, and addiction studies. Six sets of search terms were cross-referenced using Google Scholar and the Harvard Hollis Library Catalog:

Set One	"ADHD"
Set Two	"substance use disorder" OR "SUD" OR "substance" AND "addiction"
Set Three	"music training"
Set Four	"delay discounting" OR "delay" AND "discount" OR "delay" AND "reward" OR "delay" AND "gratification"
Set Five	"inhibitory control" OR "inhibition" OR "disinhibition"
*Set Six	"child"

Searches were performed using the Boolean operator "AND" and combined terms from two or three sets at a time. **Studies done on children were prioritized when available.*

Peer-reviewed journal articles, meta-analyses, systematic reviews, literature reviews, translational studies, dissertations, and theses from the past ten years were referenced. Exceptions were made for a few seminal studies. Studies that specifically examined inhibitory control and/or the ability to delay rewards in the context of ADHD and SUD, MT and ADHD, or MT and SUD were included. Studies that assessed the effects of MT on general executive functioning were only included if they also specifically measured inhibitory control. Studies that involved instrumental or orchestral MT were included. Thus, literature on the effects of other music-based interventions (e.g., music listening, music therapy, gamified music education, rhythmic movement-based activities) on ADHD and/or SUD was excluded. Though vocal training may be considered a form of MT, it was excluded as this literature review focused on instrumental MT.

Both forward and backward searches were used to ensure both foundational and state-of-the-art studies were included. For more recent meta-analytical and review studies, references were examined for additional sources. Meanwhile, for highly cited, older articles, the "cited by" feature on Google Scholar was used to identify related, more up-to-date studies. Studies found from both these methods were ensured to meet the exclusion and inclusion criteria.

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ANALYSIS

The literature review reveals the complex relationship between ADHD, SUD, and MT. The analysis section examines both direct and indirect interactions (via inhibitory control and reward delay) between these conditions. Additionally, expected and unexpected findings are reported.

Age-Related Problematic Alcohol Use

Interestingly, there emerged an association between problematic alcohol use in individuals with ADHD and their age from the literature. While children with ADHD may not necessarily be more likely to use alcohol than those without ADHD, they may be more likely to develop an abuse or dependence disorder on it (Lee et al., 2011). As these children transition from adolescence into adulthood, problematic substance use may become increasingly prevalent. Indeed, adolescents with ADHD may report alcohol intoxication nearly twice as often as those without the disorder (Mustonen, 2023). By adulthood, individuals with childhood ADHD may be more than twice as likely to report problematic alcohol use compared to non-ADHD peers (Groenman et al., 2017). Furthermore, alcohol use may tend to occur in younger-aged individuals with ADHD, who also may face increased legal issues compared to their cannabinoid-/benzodiazepine-using counterparts (Spera et al., 2020). Therefore, there may be an inverse correlation between the age of ADHD onset and the likelihood of developing and the severity of an alcohol-related disorder (Groenman et al., 2017). If so, the earlier ADHD symptoms are addressed, the lower the risk and severity of problematic alcohol use.

Leveraging Rewards to Mitigate Delay Aversion

Although delay discounting may be present in children with ADHD (Scheres et al., 2024), unexpectedly, it may be mitigated when sufficiently motivating rewards are offered (Marx et al., 2021). Aversion to delay in-and-of-itself may explain why individuals with ADHD tend to make an impulsive decision. That is, they may choose the immediate, albeit smaller, reward to avoid having to wait for the larger one, not necessarily because they desire instant gratification (Marx et al., 2021). However, if a reward is motivating enough, individuals with ADHD may better tolerate the wait and resist the small, immediate choice (Marx et al., 2021). This finding has important implications for interventions seeking to facilitate the development of delayed gratification in children with ADHD. These interventions should offer a prolonged, worthwhile reward that may potentially help children with ADHD overcome their aversion towards and even recognize the value of waiting. In doing so, these interventions may condition children to resist short-term pleasures and instead pursue more meaningful, long-term goals.

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Participant Age and Training Duration Influence Inhibitory Control Outcomes

Unexpectedly, the literature presented mixed evidence about the effectiveness of MT on improving children's inhibitory control (Fasano et al., 2019; Hogan et al., 2023). However, there is a consensus that its benefits are heavily contingent on contextual factors such as training environment and instructor quality (Hogan et al., 2023; Jamey, 2024) and training duration (Lu et al., 2025). Moreover, the optimal duration of MT for improving inhibitory control varies across demographics. Short-term (months-long) MT may be sufficient to foster inhibitory control in children (Fasano et al., 2019; Lu et al., 2025), while young adults with ADHD may benefit from long-term (years-long) MT (Raz, 2024). Though children without ADHD and young adults with ADHD may both exhibit deficient inhibitory control, their struggles stem from different sources and thus require different solutions.

Given that ADHD emerges in childhood and is characterized by impulsivity, adults with this condition may have struggled with inhibiting impulses for a long time. Therefore, longer MT interventions may be required to modify this ingrained behavior (Raz, 2024). Meanwhile, children may struggle with inhibitory control because they are still developing this ability. Additionally, childhood may be a sensitive period for developing executive functions, in which individuals may be particularly receptive to MT. Consequently, children may not need as much MT to experience significant improvements (Fasano et al., 2019; Lu et al., 2025). In sum, MT is not one-size-fits-all. The literature may be interpreted to suggest that the later an individual begins MT, the longer the MT should last to improve inhibitory control.

Inconclusive Evidence on Music Training for Children with ADHD

Unexpectedly, while there is a comprehensive body of literature on the impact of MT on inhibitory control in children and in individuals with ADHD, few studies have focused on children with ADHD. Similarly, research on the impact of MT on delayed gratification in children with ADHD remains scant. Moreover, these existing studies cannot give evidence to establish a causal relationship due to methodological limitations. For example, Tedesco (2023) included only ten participants, had no control group, and did not directly measure inhibitory control or delayed gratification. Thus, findings from Tedesco (2023) cannot be used to draw definitive conclusions. Instead, they highlight the need for further research, specifically on the impact of MT on children with ADHD.

CONCLUSION

The research question remains: "How and to what extent can MT for children with ADHD impact their likelihood of developing SUD?" This question is addressed quantitatively and qualitatively from a

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transdisciplinary Mind, Brain, Health, and Education (MBHE) perspective. The first section reports on MT's impact on SUD risk in children with ADHD and its magnitude of effect. The limitations of the research process and findings are then acknowledged, followed by recommendations for future research directions.

How Music Training May Impact SUD Vulnerabilities in Children with ADHD

As expected, MT may serve as a potential protective factor against the incidence of SUD in children with ADHD by facilitating the development of inhibitory control. However, unexpectedly, MT may not necessarily remediate delayed discounting. Both these abilities are implicated in ADHD and serve as risk factors for developing SUD (Cavicchioli et al., 2022; Marx et al., 2021).

Orchestral training programs like Music 'n' Play may help foster real-world inhibitory control (Fasano et al., 2019; Hogan et al., 2023) and delayed gratification skills. During orchestra rehearsals, students must resist the urge to play their instrument or sit patiently in silence when waiting for their turn to play (Fasano et al., 2019; Hogan et al., 2023). Furthermore, these rehearsals typically culminate with a final concert, which may serve as a motivating and rewarding long-term goal that may help children with ADHD overcome their aversion to waiting. Children are expected to attend regular rehearsals and practice independently in preparation for this concert. In doing so, they may learn to resist short-term temptations or distractions. Thus, orchestral training may effectively foster these self-regulatory skills.

Additionally, MT may have many other benefits, including improvements in executive functions such as working memory and cognitive flexibility (Jamey et al., 2024; Hogan et al., 2023; Lu et al., 2025), sustained attention, and impulse control (Raz, 2024) as well as reductions in hyperactivity-impulsivity (Fasano et al., 2019). However, my conclusion that MT may protect against SUD risk in children with ADHD by helping them develop inhibitory control is not definite. This speculation is primarily based on research on children without ADHD and adults with ADHD due to the lack of robust research specifically focused on children with ADHD.

The Extent to Which Music Training May Impact SUD Vulnerabilities in Children with ADHD

Similarly, the answer to "to what extent" MT remains unclear. Although many quantitative studies were reviewed, a clear, direct correlation was established only between ADHD and SUD. Few studies, if any, examined the direct impact of MT on ADHD or on SUD prevention. While MT is occasionally used as an intervention for ADHD, it remains less commonly researched and implemented for SUD prevention. Given the available literature, these conditions could only be indirectly linked through two mediating factors. Furthermore, the effects of MT on inhibitory control and delayed gratification in the demographic in question have yet to be investigated. Therefore, the extent to which MT may reduce SUD risk in individuals with ADHD

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cannot be determined. However, should MT be proven to confer such a benefit, it may have a broad scope of impact. High-quality MT and instruments are becoming increasingly accessible to at-risk children thanks to programs like Music 'n' Play (Fasano et al., 2019; Hogan et al., 2023). Thus, MT may serve as an accessible, long-term protective intervention for a wide range of children with ADHD.

LIMITATIONS OF THE STUDY

The seven-week timeframe constrained the breadth and depth of this literature review. Socio-emotional factors linking ADHD to SUD, as well as socio-emotional outcomes of MT, were not explored. Neural processes related to ADHD, SUD, and MT (e.g., dopamine pathways) could have been examined more thoroughly. Relevance of the literature to the research question was prioritized over recency, resulting in the inclusion of several studies published before the ideal five-year range (Fasano et al., 2019; Groenman et al., 2017).

RECOMMENDATIONS FOR FUTURE STUDIES

While this study sheds light on the potential benefits of MT for children with ADHD, its limitations highlight the need for further research. Future studies should investigate the impact of MT on larger sample sizes of children with ADHD and examine whether MT directly mitigates SUD risk within this population. Additionally, it may be worthwhile to compare the relative effectiveness of different types of MT (e.g., long-term versus short-term, individual instruction versus ensemble participation). Given the transdisciplinary nature of this study, collaboration among music educators, developmental psychologists, and substance abuse counselors is recommended to design protective interventions for children with ADHD. These interventions should target the inhibitory control and reward-regulation deficits that predispose children with ADHD to SUD.

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