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RESEARCH ARTICLE

The Potential of Music Training to Improve Attentional Control and Inhibitory Control in Children with ADHD

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Research has documented how music training boosts executive functioning and that music therapy has been associated with a reduction in symptoms of Attention–Deficit Hyperactivity Disorder (ADHD). This paper reviews the evidence on whether music training has the potential to improve two executive functions—attentional control and inhibitory control—in children with ADHD. As the research on how music training affects children with ADHD is limited, studies on the benefits of music training for similar neurodiverse conditions and the effect of music training on attention and inhibition in neurotypical individuals were reviewed. This data may act as preliminary evidence for how music training may benefit children with ADHD, but further research must involve these children to confirm that these findings apply to them.

Keywords: ADHD, attention, children, inhibition, music training

This literature review will explore the evidence that substantiates the potential of music training to improve attentional control and inhibitory control in children with ADHD. Musicians are believed to have increased attentional and inhibitory control because of procedural performance techniques developed while practising musical instruments (Hallberg et al., 2017). Research on practice and performance reveals that expert musicians shift their focus of attention between levels of musical structure as they practice, which allows attentional skills to develop (Joret et al., 2017). Managing several kinds of visual stimuli such as reading the score, interpreting the body language of the conductor and accompanying musicians, and playing an instrument may contribute to the development of divided attention (Rodrigues et al., 2013). Musicians must constantly start, stop, and repeat (actions that require inhibition) as they practice and review their technique and performance (Chaffin & Logan, 2006). The inhibition of impulses is also required to perform with other musicians as it involves group cooperation (Joret et al., 2017). Given that musicians have demonstrated elevated attention and inhibition, it is possible that music training could improve these skills in children with ADHD for whom attention and inhibition are impaired.

While evaluating the role of musical interventions, it is crucial to distinguish between music therapy and music training. Music training is a type of formal instruction in playing a musical instrument or singing. Music therapy, however, is a type of psychotherapy that is defined as "a systematic process of intervention wherein the therapist helps the client to promote health, using musical experiences and the relationships that develop through them as dynamic forces of change" (Bruscia, 1998, p. 20). While music therapy incorporates music training and has been found to reduce symptoms of ADHD (Cripe, 1986; Montello & Coons, 1998; Rickson, 2006), it is conducted specifically in clinical settings by a licensed practitioner. Music training, on the other hand, can be conducted in non-clinical settings by music teachers as they do not integrate therapeutic interventions.

Given that the literature focusing explicitly on the impact of music training on attention and inhibition in children with ADHD was limited, studies that evaluated the benefits of music training in neurodiverse samples such as Autism Spectrum Disorder (ASD) and Down Syndrome were included because ADHD shares certain characteristics with these cognitive conditions. While ADHD and ASD are

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separate cognitive impairments, they share several features and pathophysiological conditions such as abnormal patterns of neural connectivity, sensory processing difficulties, motor and impulse control issues, and sleep disturbances (Kern et al., 2016). Both conditions also have male-biased incidence. The Diagnostic and Statistical Manual of Mental Disorders does not include attention as a core deficit of ASD (American Psychiatric Association, 2013), however, researchers have found that difficulties in attention skills have been identified in individuals with ASD (Ames & Fletcher-Watson, 2010; Ravizza et al., 2013). Decreased attention, impulsivity, and hyperactivity are frequently reported in both children with ADHD as well as children with Down syndrome, and the prevalence of ADHD among children with Down syndrome has been reported to be as high as 43.9% (Ekstein et al., 2011). However, these studies focused on how music training improved speech production, concentration, on-task behaviour, and communication skills rather than the variables relevant to this research – attention and inhibition.

To understand the relationship between music training, attention and inhibition specifically, studies involving neurotypical samples that focused on these cognitive functions were reviewed. At the end of the review, certain studies that contain conflicting evidence are compared and a discussion is included with the takeaways from these studies.

Attention and Inhibition Impairment: Neurological Evidence for ADHD

Attention and inhibition are closely related, core executive functions that are crucial for daily functioning (Diamond, 2013). According to Lindsay (2020), there are multiple types and manifestations of attention such as arousal, alertness, or vigilance; sensory attention; visual-spatial attention; visual feature attention; and attention in other sensory modalities. Other studies have suggested that types of attention include attention to speech (Janus et al., 2016), auditory attention (Fritz et al., 2007), sustained attention (Fasano et al., 2019), selective attention (Milliken & Tipper, 1998), and divided attention (Rodrigues et al., 2013). One study even found chronometric evidence for two types of attention — input attention and central attention (Johnston et al., 1995).

While attention has multiple definitions and is not a singularly defined concept (Lindsay, 2020), this review looks at attention using the following definition: "a state in which cognitive resources are focused on certain aspects of the environment rather than on others" (American Psychological Association, n.d.). This interpretation is representative of most definitions of attention in the existing literature. Attention also involves the interaction between perceiving environmental cues and the allocation of perceptual processing resources (Davidson et al, 1986). Attention is synonymous with attentional control, as it refers to the cognitive process involved in selecting relevant information and filtering out irrelevant information that may bias behaviour (Preedy, 2016).

Inhibitory control or inhibition is a cognitive process that broadly refers to counteracting behaviours preceding, accompanying, or resulting from cues (Spechler et al., 2016). In simpler terms, it is the restraint on the direct expression of an instinct (Oxford University Press, n.d.). According to Spechler et al. (2016), attentional and inhibitory control are two forms of cognitive control. It is also believed that inhibitory processes play a role in selective attention (Milliken & Tipper, 1998), a type of attention that refers to "the differential processing of simultaneous sources of information" (Johnston & Dark, 1986, p. 44).

This review will focus on the variables attentional control and inhibitory control since there is neurological evidence to suggest that individuals with ADHD have impaired attention and inhibition (Carmona et al., 2009; Curatolo et al., 2009; Spencer et al., 2002). Structural and functional magnetic resonance imaging has shown that the circuits that control attention are smaller and less active in the cortices of individuals with ADHD as compared to those without ADHD. These circuits include parts of the prefrontal cortex associated with the control of working memory, alerting, and response inhibition (Spencer et al., 2002). A three-year delay in brain maturation has been found in children with ADHD in comparison to neurotypical controls, the delay being most prominent in prefrontal regions that control cognitive processes such as attention and motor planning (Curatolo et al., 2009). In children with ADHD, it has been found that the volumes of the right and left ventral striatum—areas of the brain associated with symptoms of hyperactivity-impulsivity—are significantly reduced (Carmona et al., 2009). The volume of the right ventral striatum was also found to negatively correlate to maternal ratings of hyperactivity/impulsivity. This neurobiological evidence that points to impaired attention and inhibition in those with ADHD highlights the relevance for behavioural interventions to improve these executive functions.

Cognitive Benefits of Music Training

Music education has been shown to be a potential method to improve executive functioning as it activates multiple cortical and subcortical brain areas, including the prefrontal cortex which is linked to

executive functioning (Dumont et al., 2017, Särkämö et al., 2014). A literature review conducted by Dumont et al. (2017) found that music training can aid child development and cognitive functioning as it may influence academic, cognitive, social, motor, and language skills. Music training is believed to enhance planning, working memory, inhibition, and cognitive flexibility, as studied in neurotypical children (Dumont et al., 2017). An inverse correlation has been found between performance in tests of visual attention and age at the commencement of musical studies, suggesting that music interventions would be particularly effective if administered earlier rather than later in life (Rodrigues et al., 2013).

Since attention and inhibition are crucial executive functions that are impaired in those with ADHD and music training has been shown to boost executive functioning, this paper will review the literature that may suggest that music training has the potential to improve attentional control and inhibitory control in children with ADHD. Given that the literature focusing specifically on how music training impacts these executive functions in children with ADHD is limited, this review will incorporate studies using neurotypical samples and samples with neurodiverse conditions similar to ADHD.

Methods

Fifteen studies were selected that analysed the impact of music training on neurodiverse and neurotypical samples. A manual search using the keywords and phrases 'Music training and ADHD', 'Benefits of music training, 'Music training and attention', 'Music training and inhibition', 'Learning musical instruments and ADHD', 'Music training and autism', 'Music training and ASD', and 'Music training and Down syndrome' was performed using Google Scholar to detect the relevant literature for this review. This search was conducted from June 2021 to January 2022. Studies that focused specifically on the effect of learning, playing, and making music were selected and the exclusion criteria were studies that analysed the effects of music therapy as a whole, rather than the isolated impacts of learning and playing music. For studies that included neurodiverse samples, the inclusion criteria were individuals who met the diagnostic criteria for the relevant disorder.

Results

The Impact of Music Training on Children with Neurodiverse Conditions

Typically, large sample sizes are used in psychological studies to ensure that the results are generalisable to the wider population. However, to the researcher's knowledge, there is only one case study that assesses the effect of learning a musical instrument on a child with ADHD. This study assessed how learning to play a musical instrument would benefit an eight-year-old child diagnosed with comorbid autism spectrum disorder, ADHD, sensory processing difficulties, dyslexia, and dyspraxia (Rose et al., 2018). After learning the tenor horn for nine months, the child showed improvement in his motor skills, fluid intelligence, and musical progress, but a decline in executive functioning and social-emotional behaviours between pre-testing and post-testing. This decline could be attributed to the fact that the child had numerous neurological disorders which may have worsened his executive functioning and social-emotional behaviours over time. Since the child was diagnosed with several psychiatric disorders, the relationship between music training and ADHD cannot be derived from this study.

While the literature highlighting the relationship between music training and ADHD is limited, studies have shed light on how music training can impact children with other neurodiverse conditions such as ASD and Down syndrome. Studies have analysed how music training improves verbal production, on-task behaviour, and communication skills in children with ASD (Lim, 2010; Ichinose et al., 2016; Mizuno & Sakuma, 2013).

One study compared the effect of music training, speech training, and no-training on the verbal production of children with ASD (Lim, 2010). 50 participants were randomly assigned to one of these three conditions and the intervention lasted three days. The children in the music training group watched a music video containing six songs and pictures of 36 target words. Those in the speech training group watched a speech video containing six stories and pictures, and those in the control group did not receive any training. While participants in both music and speech training groups had significant increases in production from pre to post-test, low-functioning participants showed a greater improvement after the music training than the speech training. These results suggest that children with ASD perceive crucial linguistic information that is embedded in music stimuli to produce functional speech (Lim, 2010). In other words, children with ASD may be able to transform the information that they receive within musical patterns into speech patterns. Thus, music may be an effective tool for children with ASD to improve their vocabulary acquisition and speech production.

Another study provided preliminary evidence as to how a system that links an electronic musical instrument called Cyber Musical Instrument with Score (Cymis) to a game device called the Kinect can

aid children with ASD by improving their collaboration skills and on-task behaviour (Ichinose et al., 2016). The Cymis and Kinect allow those who do not know how to read a musical score to create music by making certain physical movements. These movements are processed by an interface and converted into sound. The system allows those with neurological, motor, and cognitive impairments to enjoy making music, and participants can improve their playing with practice. The researchers proposed that the Cymis could integrate sensory and motor systems. The system was tested on a child with ASD, aged eight, and a child that was not formally diagnosed with ASD but had exhibited special cognitive-related needs common among children with ASD, aged six (Ichinose et al., 2016). The researchers found that the children were interested in visual feedback and were aware of when the music began and if there were any interruptions in the music. This taught them to recognise cause and effect. The system also effectively facilitated concentration and on-task behaviour in an enjoyable way.

Research has also analysed how music training can improve communication skills and fine motor abilities in those with Down syndrome. A study looked at how playing the wadaiko—a Japanese drum—improved interpersonal communication (Mizuno & Sakuma, 2013). The participants were two male individuals with Down syndrome who were 16 and 25 years old. They were part of a wadaiko playing group in which the members had a variety of neurodiverse conditions including ASD, intellectual development disorder, mood disorder, and Rubinstein-Taybi syndrome. The group's performances were recorded and their movements were analysed. The researchers found that duet practice of the wadaiko enhanced synchronized motion in those with cognitive disabilities. The synchronized gestures of the wadaiko performance were thought to be a significant factor in drawing the participants' attention to others and encouraging interpersonal interaction and nonverbal communication in those with limited communication skills (Mizuno & Sakuma, 2013). The members of the wadaiko group improved their ability to communicate through eye contact, gesturing, rhythm, and shouting. The participants' ratings of well-being and confidence were also elevated after wadaiko practice. This study indicates how a musical instrument in a group environment may increase communication skills in those with Down syndrome.

The success of these studies in treating neurodiverse children offers promising evidence as to how music training may benefit children with ADHD since ADHD shares certain features with ASD and Down syndrome. However, these studies do not specifically analyse attention or inhibition. Thus, studies conducted on attention and inhibition in neurotypical samples were reviewed to understand the impact of music training on these specific cognitive functions.

The Relationship Between Music Training and Attention in Neurotypical Individuals

Existing research suggests that learning a musical instrument and music training programs can increase attentional control. Overall, these studies have come to the following conclusions. Firstly, children who underwent a violin training program improved in attentional control (Hallberg et al., 2017). Secondly, rhythmic synchrony was associated with higher attention, better inhibition, and fewer ADHD-like behaviours, such as inattention, hyperactivity, and impulsivity (Khalil et al., 2013). Lastly, long-term musical training may improve different forms of visual attention (Rodrigues et al., 2013).

One study assessed the impact of music instruction on working memory and attentional control in kindergarten children (Hallberg et al., 2017). A total of 48 participants were randomly assigned to be taught violin using the Suzuki method—a music curriculum and pedagogy—for five weeks (intervention condition) or to receive no intervention (control condition). The study found a statistically significant decrease in the mean pre-post change score on the Kiddie Connor's Continuous Performance Test that measures attentional control between treatment and control groups, meaning that the children who were taught violin demonstrated better attentional control after learning to play the instrument. However, no difference in working memory was observed between the two groups. The researchers concluded that attentional control may be improved if music instruction is introduced during early childhood.

Another study quantified a specific component of music—rhythmic synchrony—and investigated the correlation between rhythmic synchrony and attention behaviour (Khalil et al., 2013). Impaired temporal processing has been posited as a cognitive marker of ADHD (Castellanos & Tannock, 2002) and a measure of temporal processing can be found in rhythmic elements of music practice (Khalil et al., 2013). In the study, 102 students aged seven to 12 were measured on their ability to synchronise using specially wired instruments designed to record each mallet strike of the participants. This test was conducted in a group music class as an efficient and ecologically valid way to measure the children's abilities. Results of the study revealed that those who performed better on the synchronising test were also more attentive, demonstrated better inhibition, and

showed less ADHD-like behaviours. This suggests that there is a significant correlation between rhythmic synchrony and attention behaviour. The findings of this research may indicate that music practice could boost rhythmic synchrony and thus, temporal processing, which may improve attention in those with ADHD (Khalil et al., 2013). However, experimental research is required to establish a causal relationship.

The effects of music training are not only evident in children, but in adults as well. A study assessed the impact of long-term musical training on different forms of visual attention ability by comparing test scores of 38 adult musicians and 38 non-musicians (Rodrigues et al., 2013). While musicians performed better than non-musicians on all tests for visual attention, the difference was statistically significant in four variables of these tests involving accuracy and reaction time in measures of selective attention, divided attention, and sustained attention. Selective attention is the ability to enhance relevant signals and manage distractions (Stevens & Bavelier, 2011), divided attention is the ability to process more than one piece of information at a time (Cristofori & Levin, 2015), and sustained attention is the ability to focus on tasks for an extended period of time (Timmers, 2014). These results clearly indicate that musicians display higher visual attention than non-musicians. The study also found a significant inverse correlation between the age of commencement of musical studies and performance in visual attention tests for three variables. This suggests that musical interventions will benefit children with ADHD more than adults. The researchers concluded that since musical practice may involve different attentional demands at different moments, long-term musical training may improve different forms of visual attention ability.

The current literature that evaluates the link between music training and attention has found a positive correlation between these two variables in neurotypical samples. This suggests that music training may be an effective intervention for children with ADHD since impaired attention is a symptom of the disorder.

The Relationship Between Music Training and Inhibition in Neurotypical Individuals

Existing research suggests that music training programs can increase inhibitory control. These studies have come to the following conclusions. Firstly, early childhood music and movement programs may improve self-regulation in pre-school children (Winsler et al., 2011). Secondly, short-term musical training may facilitate the development of inhibitory control (Fasano et al., 2019). Lastly, a school-counsellor led group drumming program has been found to improve multiple domains of social-emotional behaviour including ADHD-related issues (Ho et al., 2011).

Music training has been found to improve self-regulation in children between the ages of three and four (Winsler et al., 2011). Behavioural self-regulation in children refers to the ability to "plan, monitor, and guide goal-directed behaviour in accordance with social and contextual norms" (Winsler et al., 2011, p. 275) which includes inhibitory control and delayed gratification. In this study, self-regulation was compared in 89 children that were enrolled in Kindermusik —a publicly available early childhood music and movement program— and children who were not. Kindermusik engages children (newborn to age seven) in developmentally appropriate weekly music and movement classes. It involves singing, moving, dancing, and playing instruments together. The mean length of involvement in Kindermusik was ten months. Self-regulation was tested using developmentally appropriate inhibitory control tasks which involved delay/waiting, slowing down motor activity, and initiating or suppressing one's activity to signal. The study found that children above the age of four that had attended Kindermusik classes showed greater skills in behavioural self-regulation than the children who did not have Kindermusik experience. However, it's possible that the positive effects of Kindermusik fade over time, as children in Kindermusik demonstrated higher self-regulation if they were currently enrolled in Kindermusik (regardless of age) compared to those who were no longer. Amongst the children who had experienced Kindermusik, those who had taken more semesters of the class and had been enrolled for a larger proportion of their lives had stronger self-regulation, especially amongst the four-year-old participants (Winsler et al., 2011). Thus, the intervention may be more beneficial if administered continuously. Gender differences did not impact self-regulation in this study. The study concluded that young children who have considerable experience modulating their motor behaviour through songs and musical activities that involve inhibitory control may be able to control their behaviour better than those who do not have this experience. This intervention could be beneficial for children with ADHD as it can improve inhibitory control early in children's lives and can be made easily available in early childhood settings, such as preschools, kindergartens, and child-care centres.

While long-term musical education is beneficial, even a short, intense period of orchestral music training has been found to facilitate the development of inhibitory control by modulating levels of self-reported hyperactivity (Fasano et al., 2019). In a study

that recruited 113 children who were eight to ten years old, one group of children underwent ten sessions of orchestral training over three months while the other control group received no intervention. The researchers aimed to explore the near and far transfer effects of short orchestral music training. Near transfer effects are the transfer of skills occurring between similar learning contexts and far transfer effects are the transfer of one set of skills to another set of skills that are different from it (Biasutti & Concina, 2013). Concerning the near-transfer effects, results revealed that the music group was associated with an increase in inhibitory control scores. Children who underwent music training had a clear-cut improvement in the Walk/No-Walk test which required selective attention, sustained attention, and inhibition of an ongoing response. Although there was no significant effect of this music program on inattention and impulsivity as perceived by the children, a far-transfer effect of this music program on hyperactivity-impulsivity was found on a rating scale that assessed the levels of inattention and hyperactivity-impulsivity. Comparing the pre- with the post-test, the children belonging to the control group showed a strong increase in hyperactivity-impulsivity over the three months that was not found in the music group. However, the effects of the program were less tangible on inattention as rated by the teachers since a significant reduction of inattention was found from pre-to post-test in both groups. While long-term music programs can be difficult for children with ADHD to participate in, financially draining, and require a large amount of parents' time, this study suggests that the positive effects of music training could still possibly be achieved through shorter programs which makes it accessible to children who would otherwise not have access to it.

An advantage of musical instruction as a behavioural intervention for ADHD is that it can be administered to children of diverse cultures and socioeconomic backgrounds as well as in non-clinical settings. In a study that assessed the impacts of a school-based group drumming program, researchers sought out a method to improve the social and emotional behaviour of low-income youth that was culturally relevant, an integral part of diverse cultures, supported the value of collectivism, and did not carry the stigma of therapy that exists, particularly in non-white communities (Ho et al., 2011). This study assessed the effect of 12 weeks of school counsellor-led drumming on social-emotional behaviour. There were 101 participants who were in two fifth grade intervention classrooms and two standard education control classrooms. The results revealed that students in the drumming program improved significantly compared to the control group in multiple domains of social-emotional behaviour such as attention-deficit/hyperactivity problems, oppositional defiant problems, attention problems, and inattention subscale. These findings suggest that music instruction can be an effective intervention for children with ADHD who do not have access to therapy, especially those coming from less privileged backgrounds.

The existing research has found music training to be effective in improving inhibition in neurotypical samples. This may suggest that music training could be a beneficial intervention for children with ADHD since impaired inhibition is a symptom of the disorder.

Comparison of Music Training Interventions to Non-Musical Interventions

Although several studies have found that music training aids attentional and inhibitory control, others suggest that educational programs can improve these outcome variables, regardless of whether the programs focus on music or another educational topic. One study aimed to explore whether the effects of music training on specific and general cognitive mechanisms (music audiation, visual attention, and processing speed) differed from the effects of another educational intervention in primary school children (Roden et al., 2014). A total of 345 participants were randomly assigned to a music training condition, a natural sciences training condition, or no intervention over 18 months. The children in the music group attended weekly school-based music lessons for 45 minutes on musical instruments of their choice as well as curriculum-based music lessons at school. The children in the natural sciences group received an extended education in natural science on topics related to the school curriculum. Performance in both groups improved continuously and significantly over time, however, the improvement in the natural sciences group was significantly higher than the improvement in the music group. While these results are consistent with the findings of the other reviewed studies which found that music training improved attention, they also suggest that these effects are greater with non-musical education programs.

In contrast to the findings by Roden et al. (2014), other researchers found that music training results in the same, if not more, improvement in attention than other training or educational programs. The first study found that a one-year strings-based instrumental program significantly improved students' learning and immediate recall of verbal information, while a similarly novel juggling program did not (Rickard et al., 2010). In the study, 89 students across five primary schools were assigned to an intensive music training program that received training for two and a half to

three years. 62 students across four primary schools were allocated to a control group that received music classes that were already a part of their educational curriculum. The students in the intensive music program received one hour of group strings classes weekly which incorporated improvisation and gameplay to encourage broader learning outcomes rather than the basic acquisition of skills required to play an instrument. Following the main study, a juggling program was introduced to one control school for an additional year. Results showed that attention improved significantly more in the intensive music training group than in the control group from the second to the third year. The juggling program did not cause any significant improvement after one year of the music program. Thus, the researchers found that a music intervention was effective in improving attention whereas an alternative skill-building program could not achieve the same result.

The second study found that four to six-year-old children who underwent music training demonstrated a higher improvement in inhibition compared to those who received visual arts training (Moreno et al., 2011). In this study, 48 children were assigned to either a computerized music training condition or a computerized visual arts training condition. The music curriculum focused on motor, perceptual and cognitive tasks and it included training in pitch, melody, voice, and basic musical concepts. The training was administered in two daily one-hour-long sessions, five days per week, for four weeks. The music group made fewer errors than the visual arts group at post-test on the Go/No-Go task which measures inhibition. These results suggest that music training may improve inhibition more than training in other topics, such as visual arts.

The third study conducted by Janus et al. (2016) compared the effects of short-term music training and second language training on executive control. Researchers recruited 57 English-speaking monolingual children between the ages of four and six who had no prior musical training or exposure to a second language. They were enrolled in either a French camp or a summer music camp for 20 days. Both training groups improved on the Visual Search Task —a task that measures attention on searches with smaller, easier, distractor sets. Only the children who underwent French training also improved on the larger, more difficult set sizes over time. However, this improvement was small and the main effect in which training helped the children in both conditions improve their control of visual search is substantial. On the Sentence Judgement task —a task that is associated with better attention to speech— both treatment groups improved in their ability to selectively attend to linguistic information in a distracting context. The results of this study suggest that a music-training intervention and a language-training intervention resulted in an equal improvement in attention.

The fourth study was a longitudinal analysis of music education on executive functions in primary school children that found that a long-term, structured music program could positively influence cognitive abilities like inhibition and planning (Jaschke et al., 2018). A total of 147 participants were assigned to one of four groups—a music training group with students who had previously taken music lessons, a music training group with students who had no prior music training, a visual arts group, or a control group that received no intervention. The interventions took place over two and a half years. The test scores of the children in the two music groups increased significantly on measures of inhibition (the Go/No-Go test), planning, and verbal intelligence over time as compared to the visual arts and no arts groups. These results also suggest that music interventions are more effective than non-musical interventions.

Four of these studies suggest that music training aids attentional and inhibitory control whereas one study found that an educational program could achieve better results. Potential reasons for this contrast are discussed in the discussion section.

Overcoming the Drawbacks of Music Training Interventions

One of the primary drawbacks of music training as an intervention for children with ADHD is that their inattention, hyperactivity, and impulsivity can create difficulties while learning. In learning environments, children with ADHD may appear distracted, struggle to follow directions, have difficulty remaining seated, talk excessively, and be impatient (de L'Etoile, 2005). A potential method to facilitate the learning process is to consider a theory that may explain the behaviour of children with ADHD—the optimal-stimulation theory. The optimal-stimulation theory asserts that for all organisms, there exists a "biologically determined optimal level of stimulation" (Zentall & Zentall, 1983, p. 447). When there is insufficient stimulation, the organism will engage in "stimulation-seeking activity" (Zentall & Zentall, 1983, p. 447). Children with ADHD appear to have a higher requirement for stimulation than neurotypical children, which may suggest that they engage in inattentive, impulsive, and hyperactive behaviours to create the required levels of stimulation (de L'Etoile, 2005). Music educators can create a suitable learning environment for children with ADHD by ensuring that it is well-structured, consistent, and predictable. This would ensure that these children are gaining stimulation only from the relevant sources.

Educators can also enhance the visual, auditory, or kinaesthetic features of a music lesson to not only allow children to identify the relevant aspects of the information, but also meet their requirement for stimulation. Physical movement such as dancing can be integrated into music lessons to provide a temporary increase in stimulation that may help children stay on-task for the rest of the lesson (de L'Etoile, 2005). By teaching music to children with ADHD in a way that engages them, they can reap the benefits of such an intervention.

Discussion

In sum, this body of literature acts as preliminary evidence for how music training may benefit children with ADHD. Based on the reviewed evidence, the music-training intervention that appears to have the most potential is one that is long-term (Jaschke et al., 2018; Roden et al., 2014; Rodrigues et al., 2013), administered during early childhood (Winsler et al., 2011), involves group interaction (Ho et al., 2011; Mizuno & Sakuma, 2013), incorporates gameplay (Ichinose et al., 2016; Rickard et al., 2010), and is aided by creative elements such as improvisation (Rickard et al., 2010) and movement-based elements such as dance (Winsler et al., 2011). Further research can combine these features into one training intervention to test whether the effectiveness of the program is boosted.

While several studies have been conducted on attention and inhibition—cognitive functions that are impaired in children with ADHD—they have used neurotypical samples. The results of these studies indicate that there is potential for music training to be beneficial for children with ADHD but the causal relationship between music instruction and attentional control/inhibitory control needs to be tested on children diagnosed with ADHD to confirm that this intervention would be an effective treatment option.

Although there are very few studies on music training that have been conducted on children with special needs, the existing research exploring this topic offers valuable insights into the potential benefits of music training on attention/inhibition in children with ADHD. Group studies act as strong evidence supporting the efficacy of music training in childhood but understanding the variability in responses to music interventions is crucial when considering how it will benefit children with special needs (Rose et al., 2018). However, such children are often excluded from these group studies since they achieve statistically outlying test scores, such as on measures of cognitive abilities. For example, Fasano et al. (2019) included a questionnaire to detect possible traits of Tourette syndrome, anxiety, depression, oppositional defiant disorder, high-functioning autism, and conduct disorder in their sample and excluded children who exhibited a certain number of these traits to ensure that the results were not skewed by possible pathologies. Similarly, Jaschke et al. (2018) mentioned that "Exclusion criteria were set at the inability to perform neuropsychological testing due to dyslexia, dyscalculia, severe deafness, and blindness or insufficient motor command of both arms" (p. 3). Given that the results from this research would arguably be most beneficial for children with special needs, their inclusion in these studies would allow a greater understanding of how music interventions could aid a neurodiverse population.

While one of the reviewed studies was conducted on a child with ADHD, he was diagnosed with several other neurological disorders so the potential effects of the music training and ADHD could not accurately be established (Rose et al., 2018). In addition, this study did not specifically focus on attentional and inhibitory control and did not include a large sample of children with ADHD. Further studies with larger sample sizes of children with ADHD and samples with children diagnosed with ADHD alone must be carried out to accurately test the relationship between music training and attentional and inhibitory control.

While there is mixed evidence on the exact relationship between gender and ADHD, gender is certainly a significant moderating factor of this disorder. For example, a meta-analysis by Hasson and Fine (2012) that evaluated symptoms of children and adolescents with ADHD found that males were significantly more impulsive than females, but no difference in inattention was found on the Continuous Performance Test (CPT)— the most frequently used direct measure of inattention and impulsivity. However, the majority of studies in this review did not specifically assess gender even though gender differences may impact the effectiveness of interventions. Since gender is relevant for understanding ADHD, future studies can evaluate gender differences while studying the relationship between music training and attention/inhibition in children with ADHD.

Possible Explanations for Differences Between Musical and Non-Musical Interventions

Studies that have found that music training improves attentional and inhibitory control often compare a music intervention group to a control group that receives no intervention. One study found that a non-

musical educational intervention yielded better attention/inhibition than a musical intervention (Roden et al., 2014), whereas others found that a music intervention resulted in the same or more improvement in attention than a non-musical intervention (Rickard et al., 2010; Moreno et al., 2011; Janus et al., 2016; Jaschke et al., 2018).

It is unlikely that the age of the participants across these five studies contributed to the differences in results since they were all between four and nine years of age, with each study balancing the ages of the participants across conditions. The gender of the participants was also matched between experimental and control conditions in each study. Cultural differences are unlikely to explain the dissimilarity since the locations of each of these studies—Germany, Australia, the United States, Canada, and the Netherlands— are all developed, predominantly Caucasian nations. Future studies can utilize populations from other cultures, such as eastern countries, to increase the generalisability of the findings.

The duration of the intervention probably did not cause the difference in results since out of four studies that found that music interventions were equally or more effective, two were long-term and two were short-term. The studies of Moreno et al. (2011) and Janus et al. (2016) took place over 20 days and those of Rickard et al. (2010) and Jaschke et al. (2018) took place over three and two and a half years respectively. The contradictory study of Roden et al. (2014) was also long-term and took place over 18 months. Thus, there seems to be no relationship between the duration of the intervention and the effectiveness of the programs.

The duration of the individual music training sessions in these studies is also unlikely to be a differentiating factor. The study that found non-musical interventions to be more effective conducted music training for 40 minutes per session (Roden et al., 2014). The other four studies which found musical interventions to be equally or more effective conducted each session for a minimum of one hour (Janus et al., 2016; Jaschke et al., 2018; Moreno et al., 2011). While the duration of the music training sessions was not standardized across each study, it is unlikely that the effectiveness of the intervention varied due to a 15 minute difference.

The topics of the non-musical educational programs may explain differences in findings. While the program focused on natural sciences in Roden et al. (2014), the topics in the other four studies were French (Janus et al., 2016), juggling (Rickard et al., 2010), and visual arts (Jaschke et al., 2018; Moreno et al., 2011). It is possible that each of these programs involved different cognitive demands. Thus, the natural science education may have demanded more attentional skills than the visual arts, juggling, and French training.

As mentioned earlier, attention is not a unified concept and there are several definitions and types of attention. While these different types of attention may overlap with one another, they may also involve different cognitive processes. In the five studies which compared musical interventions to non-musical interventions, different cognitive tests were used to measure attention in each one. Roden et al. (2014) used the D2 Test of Attention which tests attention in terms of visual scanning accuracy and speed (Bates & Lemay, 2004). Janus et al., (2016) used a visual search task that measures visual attention and a sentence judgement task that measures attention to speech. Rickard et al., (2010) used the Digit Span Forward subtest which captures attention efficiency and capacity (Fink et al., 2014). Moreno et al. (2011) and Jaschke et al. (2018) used the Go/No-Go task that measures inhibition which has been argued to be a component of selective attention. Since these cognitive tests measure different aspects of attention, it could explain the difference in results between the five studies. Further research can be conducted to examine whether the results would vary if the same cognitive test for attention was used.

These inconsistent findings highlight the requirement for more research to be conducted that compares musical interventions, non-musical skill-building interventions, and non-musical educational interventions, to test whether music training specifically impacts these outcome variables, or whether any interventions can result in such improvement. Further research should also test whether music training improves specific types of attention instead of attention in general.

Conclusion

The reviewed literature suggests that music training has the potential to be an effective, safe, stigma-free, and long-term intervention to improve attentional control and inhibitory control in children with ADHD. The evidence that displays how music training has improved attention and inhibition in neurotypical individuals and those with neurodiverse conditions provides promising opportunities for future research that can explore how music training can improve these executive functions in children with ADHD.

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Conflicts of Interest

The author has no conflicts of interest to declare.

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