Music Therapy as a Non-Pharmacological Intervention for Attention Span in School-Age Children and Adolescents with ADHD: A Scoping Review of Neurobiological Evidence

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I. Abstract

ADHD (Attention Deficit Hyperactivity Disorder) is a neurodevelopmental disorder, whose symptoms include impulsivity, inattention, and hyperactivity, with reduced attention span in school-aged children and adolescents (ages 5-21). This scoping review synthesizes evidence from current studies of music therapy on the attention span in this population with ADHD. Neuroimaging techniques (electroencephalogram) show that music therapy increases alpha power and decreases delta power, which correlates with increased attention span. Additionally, an increase in neurotransmitter levels of dopamine and serotonin shows the neurobiological basis for its effectiveness. The role of rhythmic elements is also being assessed for its contribution to attention enhancement, showing their effectiveness in music therapy. Music therapy improves attention span in this population without the side effects associated with pharmacological treatments like methylphenidate, which can cause appetite suppression and sleep problems. The reviewed studies are limited by small sample sizes and short intervention durations. Music therapy is a promising intervention for enhancing attention span in children and adolescents with ADHD. However, further longitudinal studies with larger sample sizes need to be conducted to ensure more robust evidence, potentially enhancing its clinical applicability.

II. Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a long-term condition characterized by impulsivity, inattention, and hyperactivity [1]. Among children and adults, ADHD is one of the most prevalent neurodevelopmental disorders [2]. ADHD primarily affects school-aged children (6-13 years old), in whom their symptoms are more obvious than in older individuals, as the symptoms could be easily observed in learning settings [1]. Epidemiological studies have shown that 6% to 8% of children are affected worldwide, with children aged from 5 to 10 being diagnosed most frequently [1]. Additionally, adolescents with ADHD also have high dependence on alcohol and illegal drugs and are more likely to drop out of school due to a lack of attention and focus [2]. ADHD individuals have a higher risk of psychoactive substance use and nicotine dependence [3]. They were 3 times more likely to retain a grade and 2.7 times more likely to drop out of high school (22.9%) than non-ADHD individuals (10.0%) [4]. Overall, the effect of drug use is detrimental, affecting not just individuals, but families and communities.

The main treatments for ADHD are pharmacological interventions. These interventions are mainly amphetamine and methylphenidate, which are commonly used as first-line treatments for ADHD. These medications can increase dopamine and norepinephrine levels in the brain to improve focus [5]. In 1994, an estimated 80% of children in the US who had ADHD were treated with stimulant medication [1]; As of 2022, children with ADHD who have received any treatment type varies from 58% to 92%. Among the children who received treatments aged 3 to 17, 53.6% received ADHD medications. However, pharmacological treatments could produce possible side effects, such as difficulty falling asleep, cardiovascular issues, and appetite suppression [6].

In understanding how music affects the brain, it is important to consider the concept of attention span, which refers to the length of time a person can stay focused on a task without getting distracted [7].

Music differs from noise. It is an intrinsic part of humans in terms of responses like pulse, rhythm, movement, and the whole range of emotions. It is composed of structural rhythms and is meaningful and controlled. It also triggers strong emotional and hormonal responses, including changes in the brain wave activity [8]. Music therapy is a non-pharmacological intervention for mental diseases in which the music therapists use music to help patients improve their health. It comes in the form of singing, listening, and instrument playing. Clinically, it is shown to improve attention span. Commonly utilized in hospitals, classrooms, and rehabilitation centers, music therapy has proven successful in treating health problems like mental health issues, autism, ADHD, and stroke. Studies confirm its advantages in terms of lowering anxiety, raising mood, and encouraging socializing [9]. Among children with ADHD, music therapy helps with concentration and attention span. It increases memory and language processing, improves both verbal and nonverbal communication, and encourages emotional expression and social contact. In contrast to pharmacological interventions, music therapy controls ADHD symptoms free of side effects from medications [10].

The age range of this review is on school-aged children and late adolescents. This range represents a developmental period for learning. Typically, it ranges from as early as 5 years old to 21 years old (late adolescents) [11][24][25].

The primary aim of this review is to examine the effect of music therapy on the attention span of children (school-aged to adolescents) with ADHD. To provide a comprehensive examination, the review is divided into four sections. The first section analyzes the genetic factors and brain changes in ADHD. The second section focuses on the pharmacological treatments of ADHD. The third section looks at how brain activity changes in response to music, particularly through the lens of neurotransmitter and brain wave changes. The last section summarizes how rhythm plays a role in music therapy.

III. Genetic Factors and Brain Changes in ADHD

Genetic factors are the main factors contributing to the causation of ADHD, and they contribute to a high 79% mean heritability rate. The gap between the mean heritability 79% and 100% suggests other non-inherited factors, such as the neurodevelopment of children and the environmental influences with biological impact. ADHD is polygenic, involving multiple genes associated with dopamine signaling. These genes include DRD4 (dopamine D4 receptor gene), DRD5 (dopamine D5 receptor gene), DAT1 (dopamine transporter gene), SNAP25 (involved in neurotransmitter release), and COMT (affects dopamine breakdown) [12]. The biological effect is mainly on the neurotransmitter dopamine, which is related to the brain's reward center. It is released when responding to stimuli that require focus [13]. Specifically, individuals with ADHD possess variants on the 7-repeat allele in exon III (VNTR) on the DRD4 gene, which reduces dopamine receptor efficiency; The variant on the 10-repeat VNTR on the DAT1 gene, which increases dopamine transporter expression and leads to low dopamine availability; and the variant Val158Met polymorphism on the COMT leading to high enzyme activity, which reduces dopamine levels due to faster breakdown of dopamine. These genetic factors lead to the disruption of the dopamine system and the reduction of overall dopamine level (dopamine deficiency) [12], which potentially leads to symptoms such as lack of concentration and tiredness [26].

ADHD is associated with reduced brain regions in the subcortical area. Recent large-scale neuroimaging analyses reveal significant reductions in the accumbens, amygdala, caudate, hippocampus, putamen, and intracranial volume (ICV) in individuals with ADHD. (See

Figure 1.) All examined brain regions–except the pallidum and thalamus–exhibit Cohen's d values below -0.10, indicating a significance in volume reduction relative to controls [14].

The overall reduction in the areas is intrinsic to ADHD, which is not due to the effect of medication, comorbid psychiatric disorders, or symptom severity. However, age affects the volume differences, where the differences are most pronounced in children. These subcortical regions are significantly smaller in the adolescent group compared to the adult group [14].

Brain Region	Cohen's d (95% CI)	p-value	Volume Reduction
Accumbens	−0.15 (−0.22 to −0.08)	4.98×10^{-9}	Significant
Amygdala	−0.19 (−0.26 to −0.11)	3.69×10^{-7}	Significant
Caudate	−0.11 (−0.18 to −0.03)	0.001	Significant
Hippocampus	−0.11 (−0.18 to −0.03)	0.004	Significant
Putamen	−0.14 (−0.21 to −0.07)	$6.36 \times 1ee0^{-9}$	Significant
Pallidum	−0.00 (−0.07 to 0.00)	0.95	Not significant
Thalamus	−0.03 (0.03 to −0.10)	0.39	Not significant
Intracranial Volume (ICV)	−0.10 (0.04 to −0.16)	0.006	Significant

Figure 1. Table of Subcortical Brain Volume Differences (ADHD individuals vs controls).
This table summarizes the results of a large-scale MRI mega-analysis comparing subcortical brain volumes between ADHD individuals and controls. Cohen's d represents effect sizes. Significant volume reduction is shown in the accumbens, amygdala, caudate, hippocampus, putamen, and ICV [14].

IV. Pharmacological Treatments and Music Therapy

The first-line medical treatment for ADHD is a stimulant known as Methylphenidate (MPH). It is FDA-approved for the treatment of ADHD in children and adults. It also serves as second-line therapy for narcolepsy in adults [27]. MPH is well-adapted by patients, and severe problems rarely occur. However, MPH is associated with less severe side effects, including sleep problems. The study conducted by Yoo et al. identifies the predictors of sleep problems. Evaluating sleep problems and other adverse effects that occurred among them. The results show different data accurately identifying the adverse effects of MPH, presenting sleep disturbances, such as difficulty falling asleep, as common side effects of MPH [15]. Unlike pharmacological treatments like MPH, which cause side effects, Music therapy has potential alternatives that could support ADHD patients without having adverse side effects. It has been suggested to improve focus, motivation, and mental health in general [16].

V. Music Therapy’s Effects on Attention Span and Neuroimaging

A. Overview of Music Therapy for ADHD

Following World War II, music therapy emerged as a new profession. It impacts a person’s attention, emotion, behavior, and communication, facilitating relaxation and enjoyment. Additionally, it reduces anxiety, physical effects, and stress. Children with ADHD have found that music therapy is a beneficial intervention with advantages, including decreased anxiety. Most importantly, music therapy enhances focus in individuals with ADHD. Two main approaches involve active music therapy, which involves playing instruments or singing, and passive music therapy, which consists of listening [16][17].

In the original research article by Jacob et al. (2021), the authors investigated the effects of music therapy and pictorial illustration on the attention span of children with ADHD. Tested with post-reading performance among learners with ADHD, there was a 96.2% variance in the performance, which means the null hypothesis was rejected. The conclusion suggested that the active participation in singing the songs (traditional folk songs) was the reason for the effectiveness [28]. In a study conducted by LingYu Liza Lee, the attention span of children with ADHD was tested before and after with music therapy. Participants were scored on a 5 scale with 1 indicating paying less than 40% attention of the time across categories. And a 5 indicating paying full attention at the time. In the experiment A associated with attention span, results showed a significant increase from the pre-test to post-test, with an increase from score 1 to 3. As a result, the findings of the study revealed that practicing musical instruments and musical storytelling could be a tool for enhancing the attention span of ADHD children. Additionally, the sound of instruments like rain sticks, ocean drums, and thunder tubes could get children’s attention [29].

B. Neurotransmitter Changes: Dopamine and Serotonin

Serotonin is a neurotransmitter that plays a key role in body functions like mood and sleep. A low level of serotonin could cause psychological health problems [30]. A chronic deficit of serotonin (5-HT) at the synapse may trigger symptoms of ADHD [31]. Physiologically, patients who have ADHD show lower blood levels of serotonin (5-HT) than those without ADHD. Symptoms of ADHD are associated with the reduction in 5-HT. It can interact with the dopamine system to control and balance impulsive actions. Previous studies have shown that auditory stimulation (the experience induced by listening to sounds, which can evoke different emotions) [32] can affect the secretion of serotonin. A study conducted by Park et al. attempts to identify music therapy’s effect on ADHD patients’ neurophysiological changes. The study divided 36 Korean adolescents into a control group and a music therapy group, with the latter receiving 50 minutes of music therapy sessions twice weekly for three months. Neurophysiological changes are measured based on 5-HT secretion, cortisol expression, blood pressure, heart rate, CDI (Children's Depression Inventory), and DHQ (Daily Hassles Questionnaire) levels. The results show higher 5-HT and lower cortisol levels in the music therapy group than in the control group. Results confirmed that CDI and DHQ values (assessments of stress and depression level) are improved within the music therapy group. Additionally, lower systolic and diastolic blood pressure and heart rate are shown in the music therapy group [10]. As shown in Figure 2, serotonin expression levels increased after music therapy in the MT G group, whereas there were no changes in the control group, suggesting the positive neurophysiological effect music therapy has on children with ADHD, presenting an alternative way of treating depression of ADHD, ultimately increasing attention span.

In a study conducted by Michele M. Moraes et al (2018), results showed that melodic music exposure significantly increased dopamine (DA) and serotonin activity in the brain. The experiment involved the use of male adult Wistar rats, where the music group was submitted to 8 music sessions (Mozart’s sonata for two pianos) at an average sound pressure of 65 dB. Control rats were handled with no exposure to music, and brains were removed immediately after the last session. Results showed that in the caudate-putamen (CPu), music increased dopamine levels and serotonin release (measured as 5-HIAA), with strong correlations between both systems–suggesting they interact during music-induced stimulation. In the nucleus accumbens (NAcc), music increased the dopamine turnover (DOPAC/DA ratio), which is linked to the peak emotional responses. These effects likely involve two separate dopaminergic pathways: the nigrostriatal tract (from SNpc to CPu, linked to movement and attention) and the mesocorticolimbic tract (from VTA to NAcc, linked to reward and motivation). These findings support that melodic music can naturally increase dopamine secretion in brain circuits involved in attention. Potentially, it suggests its use in treating dopamine-related disorders like ADHD [33].

ADHD individuals typically exhibit lower alpha power and higher delta power levels than healthy controls, reflecting reduced attention span. A study conducted by Lee et al. also indicated that music therapy has a positive effect on the attention span of ADHD individuals. With the adoption of an electroencephalogram (EEG), neurophysiological changes were evaluated within 13 children with ADHD after 8 weeks of music intervention. Results revealed a significant increase in alpha power and a decrease in delta power, which is associated with enhanced attentiveness. The changes in brainwave activity suggest the modulation of the patterns for improving attention without an increase in impulsivity. Furthermore, these EEG findings align with a reduction in the Hit Reaction Time (HRT), indicating improved sustained attention in ADHD subjects. Interestingly, the study also revealed an increase in alpha activity in the central and parietal brain regions of methylphenidate treatment in children with ADHD. This indicates that both methylphenidate and music therapy have similar effects on enhancing alpha activity; however, music therapy offers the added advantage of being free from side effects and costs [18].

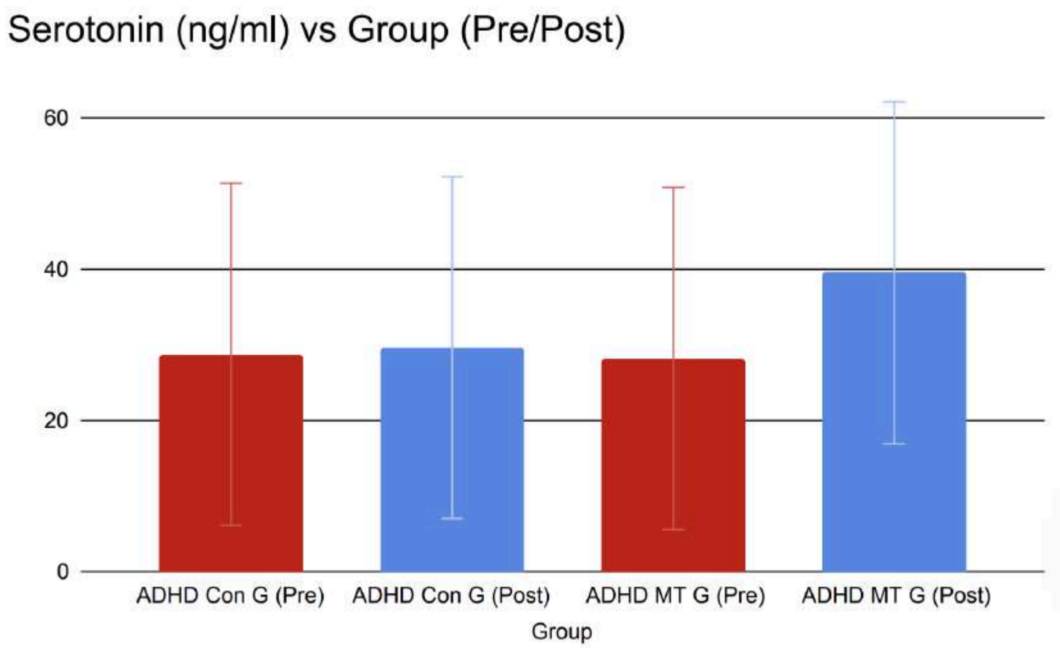

Figure 2. Serotonin (ng/ml) in ADHD Control and Music Therapy Groups Before and After Intervention. Mean serotonin expression levels (ng/ml) in the ADHD control group (ADHD Con G) and music therapy group (ADHD MT G) before and after intervention. The ADHD METG showed a statistically significant increase in serotonin levels after music therapy ($P < 0.001$), whereas no significant change was observed in the ADHD Con G. Adapted from Park J-I et al. (2023) [10].

C. Role of Rhythm in Enhancing Attention Span

Music rhythm is important in forming attention and cognitive control for ADHD individuals who have trouble focusing. It is an important part of music therapy. Research has shown that rhythm-based activities involve both reactive (bottom-up) and predictive (top-down) processing, both of which are important for controlling attention. ADHD individuals often lack control of their activities, which makes it difficult to focus [19].

The prefrontal cortex, cerebellum, and basal ganglia are among the brain systems that are shared by musical rhythm processing and attention span and are all linked to ADHD. Research on timing deficits in ADHD shows that people with ADHD frequently have problems with motor timing, beat synchronization, and rhythm perception. As dopamine regulates brain synchronization and time perception, rhythm processing is associated with abnormalities in dopaminergic signaling. Rhythm-based therapies may help people with ADHD manage their attention by improving brain synchronization. Therapeutically, rhythmic music interventions may benefit ADHD patients by strengthening the brain's capacity to foresee and react to stimuli in a predictable way. Studies have also shown rhythmic patterns alter alpha and beta waves, improving attentional focus and decreasing impulsivity in ADHD individuals. Rhythmic aspects like drumming exercises or rhythmic cueing may be an effective music intervention to improve attention span in children with ADHD [19].

D. Neuroimaging Evidence: EEG and Brain Wave Modulation

An electroencephalogram (EEG) is a technique commonly used to diagnose individuals with ADHD. It is a noninvasive technique that measures the electrical activity in the brain using

electrodes placed on the scalp, then detects neural activity changes by measuring cerebral cortex signals. Finally, brain wave frequencies like alpha, beta, theta, and delta waves are measured to analyze the attention span. When lower alpha power and higher delta and theta power are shown, it indicates a reduced attention span [20]. Figure 3 highlights the alpha power measured using EEG. The red level indicates a higher level of alpha power, and the blue level indicates a lower level of alpha power. Notably, the C3 (left central) and O1 (left occipital) channels show a significant increase in alpha power after the 8-week music therapy intervention. Figure 4 shows the levels of delta power measured by EEG.
Similar to Figure 3, red levels suggest a higher level of delta power, and the blue level indicates a lower level of delta power. As shown after the intervention, a significant decrease in delta power is observed in the P3 channel. Together, figures 3 and 4 present the increase in alpha power and decrease in delta power after the intervention. These changes are observed in brain regions–central, occipital, and parietal lobes–that are critical for attention span. Thus, the EEG findings suggest that the music and movement intervention enhanced attention span in children with ADHD, aligning with previous literature on neurophysiological improvements following similar therapies [18].

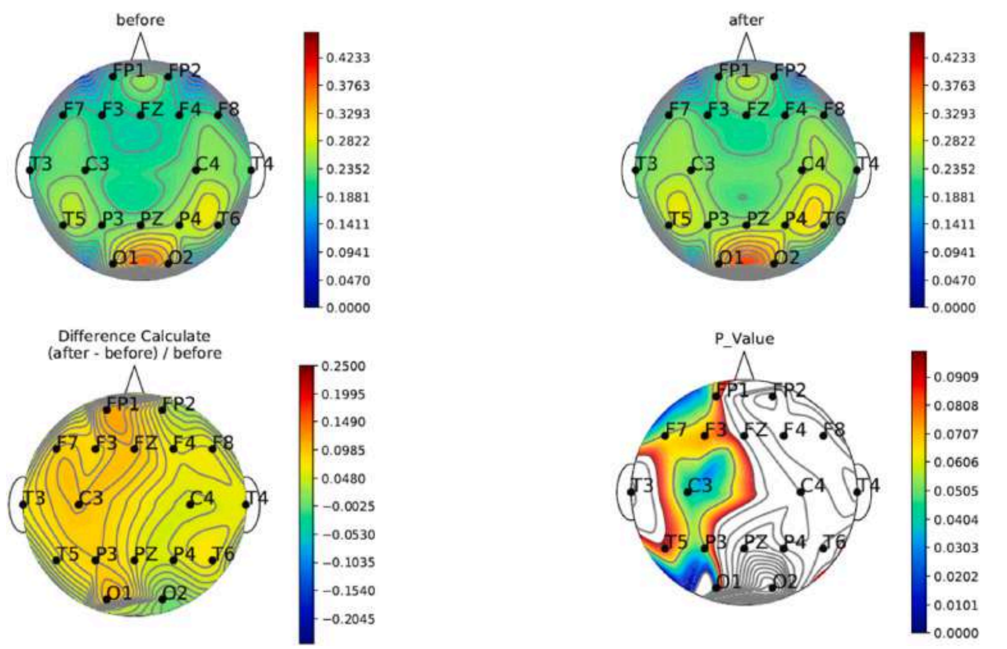

Figure 3. Increase in Alpha Power After Music and Movement Intervention. EEG topographic maps show a significant increase in alpha power following the 8-week music and movement intervention, particularly in the C3 and O1 channels. Warmer regions (red/yellow) represent higher alpha power post-intervention, indicating enhanced attention [18].

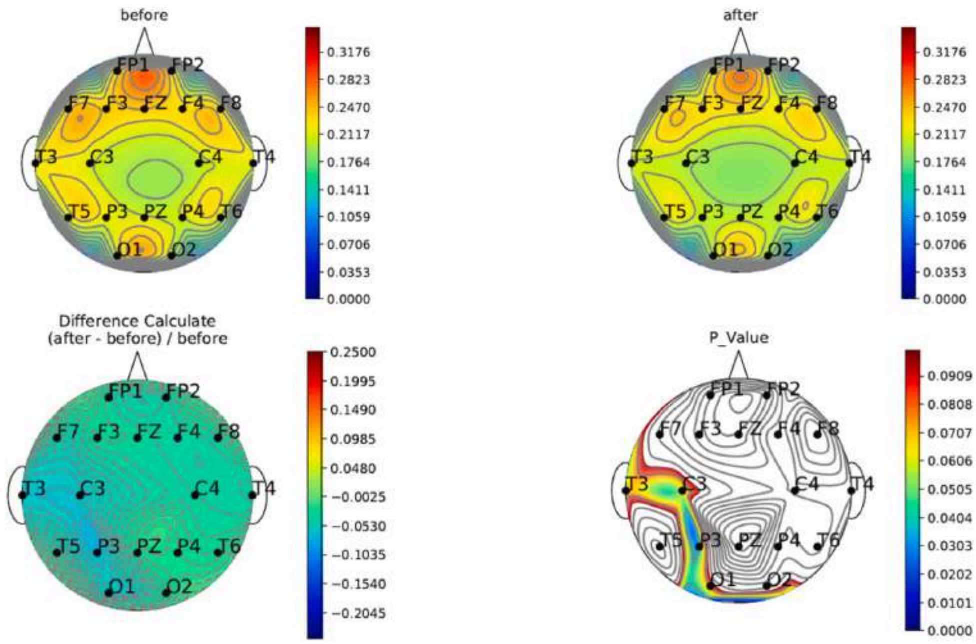

Figure 4. Decrease in Delta Power After Music and Movement Intervention. EEG analysis reveals a significant decrease in delta power in the P3 (left parietal) channel after the 8-week intervention. In the topographic map, cooler colors (blue) represent lower delta power post-intervention. A negative difference value was calculated at P3, reflecting reduced slow-wave activity often associated with inattentiveness. The reduction in delta power indicates improved attention span in children with ADHD [18].

VI. Discussion

A. Interpretation of Findings

As previously mentioned, the main contributing factor to the causation of ADHD is genes. More specifically, the polygenic characteristic of the genetic factors involved in the reduction of dopamine receptor efficiency and the promotion of dopamine transporter depression, leading to low dopamine availability. The study of the genetic contribution is robust and researched widely, consistently showing higher rates of ADHD in parents and siblings of affected probands compared with relatives of unaffected controls [23]. These studies suggested strong evidence of dopamine deficiency in ADHD individuals, and dopamine deficiency can be directly related to the reduction in attention span in ADHD individuals. Thus, it can be concluded that the polygenic factors involved in reducing the dopamine level decrease the attention span of individuals with ADHD.

When discussing the neurotransmitter secretions after music therapy interventions, two major neurotransmitters are involved: dopamine and serotonin. The deficit of both dopamine and serotonin may trigger symptoms of ADHD, such as a reduction in attention span. In Park et al. 's and Michele M. Moraes et al (2018) study (the latter research object involved Wistar rats), both tested the neurotransmitter expression levels after music therapy interventions. The two studies' results showed an increase in serotonin expression levels compared to the control group, suggesting the positive neurophysiological effect music therapy has on children with ADHD. In Michele M. Moraes et al (2018) study, in particular, involving Wistar rats, dopamine and serotonin activity in the rats' brain increased together. The finding of the two studies supports the effect that music therapy (melodic music in particular) has on neurotransmitter secretions, ultimately increasing the attention span in children with ADHD.

With the use of an electroencephalogram (EEG), observed neurophysiological changes (alpha power and delta power changes) showed a significant increase in alpha power and decrease in delta power in Lee et al.’s study after the intervention of music therapy. In Figure 3, specifically, the C3 and O1 channels showed color changes approaching red, which shows the increase in alpha power after 8-week music interventions. Stimulation medication (methyphenidate) also has similar effects on enhancing the alpha activity in the human brain. Thus, the result of the neurophysiological changes could potentially suggest the effectiveness of music therapy compared to traditional medicine treatments. Further studies around the neurophysiological changes with music interventions could be achieved to further highlight the effectiveness of music therapy on attention span in ADHD individuals.

B. Limitations of Current Studies

Using neuroimaging techniques (EEG and fNIRS), the images offer objective data supporting the effectiveness of music therapy. Rhythm-based treatments could also be especially successful in improving attention. Though promising, the present research has some constraints. Many studies evaluate the effectiveness of music therapy with small sample sizes, such as Park et al. analyzing only 36 Korean children, and Lee et al, analyzing only 13 children. The small sample sizes in the studies greatly impact the accuracy of the results. Furthermore, most research concentrates on short-term effects, so the long-term influence of music therapy on ADHD symptoms is mainly unknown. Thus, future studies that manipulate larger sample sizes and longer periods are needed to identify the accuracy of the effectiveness and successful kinds of music therapy and their long-term advantages.

C. Future Suggestions

Larger, longitudinal studies could confirm whether music therapy
The benefits of attention span persist over the years, enhancing its clinical applicability.

VII. Conclusion

This scoping review discusses the possibility of music therapy as a non-pharmacological intervention for enhancing attention span in school-age children with ADHD. By increasing the alpha power and decreasing the delta power – associated with enhanced attentional control – musical therapy alters brain activity, according to neuroimaging research. Its effect on neurotransmitter levels, including serotonin and dopamine, also points to a biological foundation for its potency. Music therapy shares a possible substitute with no side effects than pharmacological treatments like methylphenidate.

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