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The Neuroscience of Music: Disruptive Mood Dysregulation Disorder

Lara Velasquez[1] and Tracy McBride[#]

[1]Notre Dame Preparatory High School, USA
[#]Advisor

ABSTRACT

Healthcare providers advocate for active music therapy (AMT) for mental illnesses because it can be highly effective without the possible adverse effects that accompany pharmacological therapy. Though this form of therapeutic intervention has been thoroughly researched within the context of adolescent ADHD, depression, and bipolar disorder, the application of AMT within Disruptive Mood Dysregulation Disorder (DMDD) has yet to be explored. This research paper employs a secondary mixed method comparative analysis to determine whether AMT in the form of structured piano lessons is a viable treatment option for DMDD adolescents. The results indicate an overlap between the neuroscience of AMT and the neural abnormalities of DMDD. The rapid reorganization of the sensorimotor network induced by active music therapy can remedy the cognitive inflexibility that causes the irritable outbursts of DMDD youth. An increase in time engaged in practicing piano is directly correlated with an increase in gray matter density, and the amygdala relies on this gray matter to process social behavior effectively. It is evident that active music therapy has the potential to transform treatment plans for DMDD youth though further research is needed to consolidate these findings through a confirmatory clinical trial.

Introduction

Music is known as a universal language due to its timeless capacity to convey stories and inspire emotions. However, music also offers a myriad of benefits from a neurological perspective through active music therapy. Active music therapy, or AMT, is a form of therapeutic intervention in which individuals actively participate in creating music, rather than being passively exposed to music. Active engagement in playing instruments, composing songs, or even singing, allows the clients to engage in creative exploration and emotional expression in a dynamic environment. AMT programs have been proven to increase mood, expand divergent thinking, and reduce anxiety for individuals who seek mental rehabilitation. The American Music Therapy Association states that the profession of "music therapist" formally began after World War I and World War II when musicians were hired in hospitals nationwide to share their talents with suffering veterans (n.d.). The remarkable physical and emotional improvements in the veteran patients attracted societal attention to the rehabilitative potential of music, and music therapy began to evolve rapidly in the subsequent decades. Today, healthcare providers continue to advocate for AMT as an alternative therapy option for numerous mental illnesses because it can be highly effective without causing the patient to suffer the adverse effects that accompany pharmacological therapy (Shipman et al., 2016). Though this form of therapeutic intervention has been thoroughly researched within the context of adolescent ADHD, depression, and bipolar disorder, the application of active music therapy within Disruptive Mood Dysregulation Disorder or DMDD has yet to be explored.

In 2013, DMDD was introduced in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) and categorized as a depressive disorder specific to adolescents. According to the American Psychiatric Association, symptoms include severe recurrent temper outbursts occurring on an average of three or more times

each week for a minimum of one year (2013). Such outbursts are out of proportion in intensity or duration in response to the original stressor. The diagnosis must be made between ages six to ten, but symptoms may occur until age eighteen. DMDD youth showcase chronic and persistent irritability between temper outbursts, which often creates difficulty with social interactions and daily functions at home and school.

The criteria, as defined by the DSM-5, allows clinicians to identify adolescents with this disorder; however, the U.S. Food and Drug Administration (FDA) has not approved any medications for treating DMDD. The National Institute of Mental Health states that clinical trials continue to search for viable treatments that will address the specific needs of DMDD adolescents (n.d.). Current methods of treatment are derived from interventions associated with managing the symptom of irritability within other disorders such as Attention-Deficit Hyperactivity Disorder (ADHD). Health care providers may prescribe stimulants, antidepressants, and atypical antipsychotics, and they often suggest a combination of medication and psychotherapies, such as cognitive behavioral therapy. Conclusive evidence on the most effective therapeutic interventions remains to be determined.

The existing knowledge surrounding DMDD treatment from pharmacological and psychiatric approaches is being researched extensively by scientists. What remains to be explored is the efficacy of active music therapy in the form of learning piano as a viable treatment for DMDD adolescents. The scarcity of research beyond medication and common psychotherapy is regrettable because if viable, AMT can potentially remove the DMDD adolescent's dependency on volatile medications and additionally offer an abundance of benefits by learning this musical instrument. This study attempts to contribute to the existing research of active music therapy by exploring its viability in the context of DMDD.

For the purpose of this research project, I selected active music therapy in the form of engaging in weekly piano lessons. There are various music-based interventions that have been proven effective in managing mental disorders, however, I elected to study AMT in the form of learning piano because it is a popular instrument from both a scientific and societal perspective. This assumption is based on the wide variety and availability of research surrounding AMT piano programs in comparison to other instruments that have not been studied as a form of therapy. Aspiring musicians often learn piano as their first instrument because the structure of the ascending and descending notes facilitate a clear visual understanding of concepts such as pitch and melody. The physical layout of the piano encourages the development of new skills through learning scales, chord progressions, theory, or sight reading. The specific content of each structured lesson and the pace at which the individual is able to progress may contribute to different neurological responses for each client. However, my research is solely focused on the broader question of whether active music therapy in the form of these weekly structured piano lessons is a viable treatment option for DMDD youth.

Literature Review

Active Music Therapy (AMT)

Active music therapy has been thoroughly researched in the context of specific mental disorders that have existed in the DSM-5 for much longer than DMDD. The following systematic reviews consolidated existing clinical trials and experimental studies to identify general conclusions surrounding the applicability of AMT to three disorders: ADHD, depression, and bipolar disorder. Martin-Moratinos et al. (2023) concluded that active music therapy benefited patients with ADHD most prominently in the domains of social skills and impulsivity. The challenge of following the beat to create the rhythmic structure of each song involves "sensorimotor integration between predictive and reactive processing where attentional control is involved" (Martin-Moratinos et al., 2023). AMT benefits adolescents with ADHD by facilitating the communication between the senses and the brain to concentrate on how to appropriately predict and react to external stimuli. Another study concluded that

AMT decreases depressive symptoms and anxiety levels to improve daily functions such as "maintaining involvement in job, activities, and relationships" (Aalbers et al., 2017). A literature review of AMT in the context of various mental disorders by Krauss et al. (2019) acknowledged the data showed music alone lacked efficacy on patients with bipolar disorder, as the subjectively uplifting music induced complex negative emotions. The research group hypothesized that such response was a ramification of the patients' inability to regulate positive emotions, therefore creating distress that presents as a negative emotion. Despite the conflicting results, Krauss and colleagues ultimately theorized that within the context of bipolar disorder, active music therapy is a "beneficial tool allowing patients to better understand their emotions and roots therein" (Krauss et al., 2019). The mounting evidence creates a compelling argument of the rehabilitative potential of music-based intervention in the context of other mental illnesses.

Disruptive Mood Dysregulation Disorder (DMDD)

According to the American Family Physician Foundation, risperidone is commonly prescribed to DMDD patients due to its proven efficacy with irritability in autism and other disruptive behavior disorders (Arnold et al., 2018). A systematic review conducted by Arnold et al. (2018) and published in the American Family Physician clinical journal a consistent trend across eight trials, each ranging four to ten weeks: risperidone successfully reduces measures of aggression and improves overall conduct in children. Despite the efficacy of the atypical antipsychotic for adolescents specifically with behavioral issues, the adverse side effects of these medications raise concern: increase in suicidal thoughts and behaviors, weight gain, metabolic fluctuation, and hormonal changes among others. A retrospective biobank study conducted by Oshikoya and colleagues concluded nearly one in three children treated with risperidone for more than one month experienced one or more of the adverse side effects aforementioned (Oshikoya et al., 2019). With these findings in mind, it is imperative to recognize the prolonged implications of prescribing risperidone to adolescents with DMDD.

Contrary to previous studies seeking the optimal DMDD pharmacological treatment, one pediatric neuropsychiatrist achieved a significant breakthrough in the 1970s. Dr. Daniel Matthews worked with pathological juveniles in an inpatient facility and used a quantitative electroencephalogram to record and analyze brain wave activity during an individual rage episode. Matthews sought to identify the root cause of explosive rage and impulsive aggression to determine how this form of severe irritability differs from other behavioral disorders on a neurological level. Quantifying various brain wave patterns and identifying their correlations to functional abnormalities, he consolidated the information into a database that eventually became a nationwide standard, revolutionizing the way in which clinicians understand the neuroscience of DMDD. The findings suggested that DMDD youth experience heightened activity in the amygdala, the brain's emotion regulation center, due to a deficiency of dopamine (Zagorski, 2018). This neurological deficiency presents in adolescents as constant hypervigilance and poor impulse control. Focusing on increasing dopamine levels and stabilizing the amygdala activity, Matthews crafted his protocol using a combination of anti-epileptic medications alongside an antidyskinetic drug called amantadine. Amantadine is a dopamine inducer, making it the key component to this treatment approach. The Matthews Protocol, though yet to be approved by the FDA, has had a consistent success rate with 85-90% of cases experiencing improved symptoms (Revolutionize DMDD, n.d.). Current records reveal that some children have been able to progressively reduce their intake or remove the dependency on the prescription all together. Matthews Protocol is currently the leading pharmacological treatment option and clinicians continue to suggest the method when caring for DMDD youth.

Beyond the pharmacological approach, other forms of psychotherapies have early roots in achieving success. Cognitive behavioral therapy (CBT) centers on the idea of encouraging healthy behavioral patterns and avoiding maladaptive behavior in social interactions. Stringaris et al. (2017) studied how parents can intentionally apply CBT practices in the home environment by "reinforcing children's prosocial behavior" with praise, and on the contrary, admonishing temper outbursts. By identifying aggressive behavior as a learned response

that the individual must choose to avoid, children are challenged to adapt to their environment in a constructive manner (Stringaris et. al, 2017). Dialectical behavior therapy (DBT-C) is another recommended method that trains the necessary skills to properly cope with emotions and regulate behavioral outbursts. A 2017 randomized controlled trial led by Allison Knopf and published in the Brown University Child and Adolescent Behavior Letter determined that DBT-C sessions would correlate with changes in the brain's emotional processing circuitry, though the researchers suggest a confirmatory efficacy trial is needed to fully understand its potential as a treatment for DMDD (Knopf, 2017). Health care providers often suggest a combination of medication and psychotherapy to establish regularity during the initial post-diagnosis phases. The National Institute of Mental Health recognizes the rising pertinency of DMDD and is currently "funding studies focused on further improving these treatments and identifying new treatments to address irritability and temper outbursts" (National Institute of Mental Health, 2024).

Despite the ongoing research aiming to decipher the numerous treatment options for DMDD youth, mental disorders including DMDD do not conform to a uniform pattern of symptoms and can present differently with each individual case. While pharmacological therapy may prove highly effective for one adolescent, another child may necessitate a more intricate treatment plan. The comprehensive analysis of existing literature not only emphasizes the complexity of AMT, but also highlights a gap for further research. Through a mixed method comparative analysis, is active music therapy in the form of learning piano a viable treatment for adolescents with Disruptive Mood Dysregulation Disorder?

Methods

My method of research consisted of solely primary source analysis varying from academic journals, case studies, controlled experimental trials, and systematic analysis pieces. I selected an embedded mixed method design meaning the qualitative data was embedded within, or further explains, the quantitative data. By imploring a multifaceted secondary approach, I was able to conduct a comparative analysis to recognize overarching trends and commonalities to fill the existing contextual gap: active music therapy has yet to be explored in the context of Disruptive Mood Dysregulation Disorder.

In the early stages of my research project, I approached my research question attempting to establish a correlation between AMT and DMDD. However, correlational study requires data showcasing the interaction of variables for the researcher to be able to decipher the relationship between them, and the gap my research question intended to fill was the fact that AMT had not yet been explored in the context of DMDD. Therefore, I remodeled my data collection and method into a comparative analysis. The comparative analysis consisted of continuous side-by-side comparisons between sources which helped me establish my conclusion through the identification of shared neurological characteristics. This method was conducive with the secondary nature of my research, as the comparisons and inquiry that emerged from the data collection became the content of my study rather than calculating the strength or weakness of a correlational association. As a high school student confined by time and access to resources, this approach allowed me to explore a topic of personal interest without the requiring the involvement of human participants.

My embedded mixed method design was an effective way to understand DMDD from multiple perspectives. In the first phase of my research, I relied heavily upon quantitative data and the conclusions of existing scholarly work including case studies and systematic reviews. After examining the most prevalent altercations produced by active music therapy on a neuroscientific level, the second phase implored both quantitative and qualitative methods to find the neural abnormalities of DMDD. I listened to numerous podcasts with parents detailing the difficulty of raising a child with DMDD and how the diagnosis can impact the overall family dynamic. In extracting common themes from these parental accounts, I was able to grasp how the neural abnormalities are physically expressed in unwieldy behavioral outbursts. I arranged the data from both phases of research to situate the line of reasoning leading to my newfound conclusion.

Criteria for Selecting Primary Sources

In selecting my quantitative data, I used key phrases to prompt my source collection on the databases PubMed (the National Institutes of Health Library of Medicine) and EBSCO. Key words including Disruptive Mood Dysregulation Disorder, active music therapy, sensorimotor network, gray matter density, and amygdala were most prominent in my search. All studies selected were evaluated for credibility based on the author's experience, location of publishing, quality of peer-review, and reputation of academic journal if relevant. All quantitative studies included were evaluated for purpose in relation to my research question and organized based on the intention of each phase of data collection relating to DMDD or AMT. In selecting my qualitative data, I used Disruptive Mood Dysregulation Disorder as the key word while searching on Apple Podcasts. The only qualification in selecting a podcast episode was for the interviewee to be a parent of a child with DMDD. The qualitative interviews in the form of online podcasts were deemed relevant to my research study if the parental perspective provided details about managing behavior in a non-therapeutic setting and how irritable outbursts can affect the household dynamic. The names of parent interviewees were kept anonymous in the publication of the podcast episodes and are referenced by the name of the podcast interviewer or title. All sources included in this paper were published within the past three decades, with DMDD data being published in the past decade.

Intended and Expected Outcome of Research

Using existing research published by psychiatrists, psychologists, music therapists, and other researchers, I expected to identify key similarities between the neuroscience of AMT and the neural abnormalities of DMDD. The discovery of these areas of commonality would encourage researchers to explore the potential relationship between AMT and DMDD. With an understanding of the existing contextual gap and the multifaceted method I selected, I formulated my hypothesis: If structured piano lessons can improve motor coordination and stimulate cognitive processing, then active music therapy in the form of learning piano could be a viable treatment option for DMDD individuals.

Results and Analysis

The advent of music-based intervention in the last decade has transformed the scientific understanding of the human brain, specifically through the concept of neuroplasticity. Neuroplasticity refers to the ability of the central nervous system to functionally adapt to changes such as new learning experiences by reorganizing its structure and connectivity (Chatterjee et al., 2021). Active music therapy utilizes the multimodal and multisensory attribute of music to analyze neuroplasticity, and in turn, scientists can understand the neural mechanisms that aid rehabilitation. For example, an orchestra musician who dedicates more than twenty hours per week to practice their instrument will showcase structural differences in their sensorimotor network and cognitive control in comparison to the neural functions of a non-musician. An article by Constantin (2018) offers an additional perspective by explaining the relationship between neuroplasticity and music therapy as a reward system. Dopamine, a neurotransmitter, is an integral component of reward circuitry as a patient "composing and experiencing music creates a kind of synchronized dopaminergic reward that may strengthen the connections associated with related emotional expression" (Constantin, 2018). Ultimately, active music therapy has been proven to altercate and strengthen neural connectivity. The concept of neuroplasticity is integral to understanding the relationship between DMDD and active music therapy.

Phase One of Data Collection

In Phase One of my data collection, the benefits of AMT were most evident in the sensorimotor network and gray matter density. The sensorimotor network, responsible for processing external physical stimuli, is referenced often in active music therapy experiments due to the strong correlation between neuroplasticity and motor functions. In a study conducted by Pascual-Leone and colleagues, transcranial magnetic stimulation was used to observe functional reorganization in non-musician participants while they learned repetitive five-finger piano exercises. The mental imaging process was applied while subject was at rest, not performing, which illustrates the modulation of neural circuits in response to "minimal physical practice." The results of the four-week training program revealed the rapid reorganization process of cortical motor areas and how such changes induced by the learning experience can disappear when program concludes (Pascual-Leone et al., 1995).

In addition to structural changes in the sensorimotor network, changes in gray matter density over motor regions exemplifies neuroplasticity in reaction to music. Gaser and colleagues (2003) used voxel-based morphometry, a neuroimaging technique, to compare the brain anatomy of professional keyboard players, amateur musicians, and non-musicians. Specifically, differences in gray matter density demonstrated how structural adaptations occur in response to long term training and repetitive skills rehearsal. The results revealed the intensity or level of musical practice is "positively correlated with the increase in gray matter over motor regions" (Gaser et al., 2003). These motor regions are indispensable to the comprehension and execution of bimanual sequential finger movements, and overtime, musical training allows for the strengthening and refinement of neural circuitry. Additionally, the density of gray matter can be associated with the capacity to understand emotion or repair one's mood. According to the voxel-based morphometry study conducted by Koven and colleagues, lower gray matter volume is associated with inferior attention to emotion and cognitive control, therefore impairing the individual's ability to self-regulate emotions and internal experiences (Koven et al., 2011). The neuroimaging research studies led by Gaser et al. and Francois et al. confirm that music-induced plasticity has been explored extensively, as active music therapy clearly correlates to rehabilitative altercations in the brain's sensorimotor functions and gray matter density.

Phase Two of Data Collection

Phase two of my data collection involved an analysis of the neuroscience of DMDD using quantitative data and an understanding of how these structural abnormalities present symptomatically using qualitative data. A comparative study by Braenden and researchers, found that irritability is related to emotional dyscontrol and cognitive inflexibility. Irritability causes a tension between body-neural networks and if the cognitive control systems fail to regulate the increased activity, the tension releases in the form of a temper outburst (Braenden et al., 2023). In a systematic overview of the underlying mechanisms in DMDD by Coldevin et al., multiple studies found abnormalities in the left or right amygdala activation during face-emotion processing demonstrating the social processing difficulties of DMDD youth. This deficiency causes DMDD adolescents to have a bias towards angry faces and a difficult time deciphering the emotional tone of spoken conversation.

Building upon the foundational data collected in the quantitative portion of Phase 2, I discovered two key themes from listening to the podcast episodes which established an understanding of DMDD symptoms from an outward perspective rather than on a neuroscientific level. One mother explained her frustration during the years of constant trial and error process when searching for an effective treatment plan for her daughter (Staunton, 2023, 11:34). In their experience, the DMDD patient did not respond to any form of therapy until they found an effective medication plan that finally stabilized her emotions. Another podcast parent interview discussed the challenge of managing the irrational outbursts when the child ultimately cannot regulate their emotions. It can be easy to feel angry or discouraged when trying to support DMDD adolescents, however, this

parent always reminds herself that her child lacks control over normal social processing systems (Mothers on the Frontline, 2023, 6:22).

Imploring my selected method of comparative analysis, I identified an overlap between the neuroscience of AMT and the neural abnormalities of DMDD. The rapid reorganization of the sensorimotor network induced by active music therapy can remedy the cognitive inflexibility that causes the irritable outbursts of DMDD youth. An increase in time engaged in practicing piano is directly correlated with an increase in gray matter density, and the amygdala relies on this gray matter to process stress and social behavior effectively. The multitude of evidence demonstrating the neurological commonalities of AMT and DMDD indicate the potential of structured piano lessons as a treatment option for Disruptive Mood Dysregulation Disorder.

Conclusions and Future Study

The analysis of the data collected aligns with my hypothesis: Structured piano lessons can facilitate improved motor coordination and stimulate cognitive processing, therefore, active music therapy in the form of learning piano can be a viable treatment option for Disruptive Mood Dysregulation Disorder adolescents. The presentation of symptoms as described in the podcasts is directly connected with the neural abnormalities of DMDD, and furthermore, these abnormalities can be remedied by the neural benefits of engaging in active music therapy.

A limitation to my conclusion is the comorbidity of Disruptive Mood Dysregulation Disorder. Comorbidity refers to the presence of other coexisting mental health conditions with DMDD. The roots of DMDD began with the influx of youth being diagnosed with bipolar disorder at the beginning of the 21st century. Dr. Stringaris (2017) was the first researcher who isolated the symptom of "severe mood dysregulation" into a separate diagnostic category by analyzing adolescent irritability through phenotypic associations and genetic patterns conducive to depression (Stringaris). Severe mood dysregulation has always existed within the context of other mental disorders and will continue to be a symptom of adolescent depression, anxiety, and Oppositional Defiant Disorder (ODD). For example, the podcast episode with Staunton touched on the difficulty of finding comprehensive care for her daughter who also struggled with depression, anxiety, and ADHD. Comorbidity can complicate how clinicians diagnose and approach treatment as it influences the overall presentation of DMDD. Though my research concludes active music therapy is a viable treatment option for DMDD adolescents, comorbidity may complicate the efficacy of this therapeutic intervention. Future research looks to define how comorbidity can cause differing neural correlations and deficiencies in the brain, and therefore impact the influence of active music therapy for regulating DMDD symptoms.

An overall limitation I found difficult during my research process was the constraints of time and access to resources. I chose to analyze primary sources to research a topic that I was curious about, which limited the scope of my research to existing studies and public data. With an understanding of this limitation, I acknowledge my findings as a grounded theory rather than an absolute, concrete conclusion like one of an experimental study. A grounded theory is constructed from a continuous comparative analysis approach to existing data, which aligns with the secondary nature of my study and my research question overall. Future researchers should consider the commonalities between active music therapy and DMDD and consolidate my findings through a confirmatory clinical trial: a year-long program in which DMDD adolescents engage in weekly structured piano lessons and subsequently observed for symptom improvements or neural structural changes specifically in the sensorimotor network, gray matter density, and amygdala.

This study contributes to the existing research of active music therapy by exploring its viability in the context of DMDD. The neural intricacies of AMT and DMDD provide valuable insight that contribute to the progressing discovery of the most effective therapeutic approaches for Disruptive Mood Dysregulation Disorder. It is evident that active music therapy has the potential to transform treatment plans for DMDD youth by providing an option without the adverse side effects of traditional medication. Ultimately, these findings offer important pathways for further exploration and contribute to ongoing dialogue in the mental health community.

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