Music Therapy and Autism Spectrum Disorder
Literature Review

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Dissertação para obtenção do Grau de Mestre em
Mestrado Integrado em Medicina
(Mestrado integrado)

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maio de 2023

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Eu, Carolina Isabel Caldeira da Silva, que abaixo assino, estudante com o número de inscrição 39307 do Mestrado Integrado em Medicina da Faculdade de Ciências da Saúde, declaro ter desenvolvido o presente trabalho e elaborado o presente texto em total consonância com o **Código de Integridades da Universidade da Beira Interior**.

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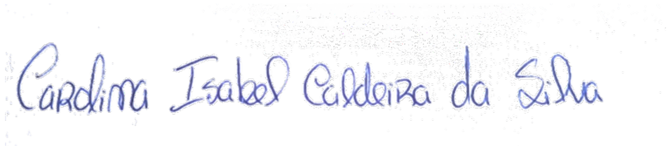

Acknowledgments

Aos meus.

Aos que tenho comigo e que levo comigo.

Aos que me querem bem.

Aos que quero bem.

Aos meus.

Abstract

Autism spectrum disorder is a complex neurobiological disorder that affects social interaction, communication, and behavior. While there is no cure, MT has emerged as one of the most effective ways to improve the quality of life for individuals with autism. Music can help with communication, emotional expression, and reducing anxiety, providing a structured and predictable environment. MT can be used as a tool for self-expression, learning new concepts, and improving motor control. However, more research is needed to develop disease-modifying therapies that target the core deficits of the disorder.

Keywords

Autism; Interaction; Behaviour; Communication; Music Therapy; Plasticity;

Resumo

A perturbação do espectro do autismo é uma condição neurobiológica complexa que afeta a comunicação, a interação social e o comportamento. As causas exatas desta condição não são totalmente compreendidas, mas está estabelecido que se baseiam numa combinação de fatores genéticos e ambientais. Nos últimos anos, a prevalência da perturbação do espetro do autismo aumentou, gerando mais atenção e pesquisas. Atualmente não há cura para o autismo, mas existem muitas maneiras de controlar e tratar os sintomas associados, por exemplo através da musicoterapia.

Este tipo de abordagem surgiu como uma intervenção promissora que pode ajudar indivíduos com autismo a melhorar sua qualidade de vida, especialmente a desenvolver capacidades sociais a nível de comunicação e interação com outras pessoas, dentro ou fora do círculo familiar. Os musicoterapeutas usam uma variedade de instrumentos e ferramentas para ajudar estes indivíduos a expressar as suas emoções e comunicar os seus sentimentos. Além disso, a música fornece um ambiente organizado e previsível que pode ajudar a melhorar o foco e, consequentemente, reduzir a ansiedade. A musicoterapia também pode ser usada como meio de ensino ativo ou passivo, visando explorar e desenvolver a autoconsciência e a autoexpressão.

Do ponto de vista neurofisiológico, a música pode também ser um caminho para desenvolver a plasticidade cortical em indivíduos autistas, ou seja, pode ajudar a reconectar os circuitos sensoriomotores cerebelares e cerebrais, melhorando o controle motor e reduzindo comportamentos repetitivos. Isto deve-se ao facto da música ter a capacidade de fortalecer as conexões sinápticas entre diferentes áreas corticais somatossensoriais do cérebro, destacando a importância do sistema de neurônios-espelho e da ínsula anterior. Embora os mecanismos do funcionamento da musicoterapia ainda não sejam totalmente compreendidos, a pesquisa sugere que pode influenciar positivamente a comunicação, a interação social e a expressão emocional em indivíduos com autismo, e isso deve motivar a novas investigações, mais precisas e direcionadas ao indivíduo em questão.

Palavras-chave

Autismo; Prevalência; Musicoterapia; Musicoterapeuta; Plasticidade; Mecanismos;

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Table List

Acronym list

UBI	Universidade da Beira Interior
ASD	Austim Spectrum Disorder
AS	Asperger Sydrome
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, 4TH Edition
PDDs	Pervasive Developmental Disorders
PDD-NOS	Pervasive Developmental Disorder-not otherwise specified
DSM-III	Diagnostic and Statistical Manual of Mental Disorders, 3TH Edition
DSM-V	Diagnostic and Statistical Manual of Mental Disorders, 5TH Edition
NDD	Neurodevelopmental Disorders
ICD-11	International Classification of Diseases
CARS	Childhood Autism Rating Scale
MNS	Mirror Neuron System
MRI	Magnetic Resonance Imaging
AI	Anterior Insula
SN	Salience Network
TEACCH	Treatment in Education of Autistic and Related Communication Handicapped Children
TDM	Transformational Design Model
ABA	Applied Behaviour Analysis
ESDM	Early Start Denver Model
AMMT	Auditory Motor Mapping Training
MIT	Music Intonation Therapy
FCMT	Family-centred Music Therapy

1 Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by impaired social interaction, communication, and restricted and repetitive behaviour. It is a complex neurobiological disorder caused by countless environmental and genetical factors, becoming more prevalent in last decades. Although it has no cure, there has been many ways to treat or control this condition, and using music is nowadays one of the best approaches. On these concepts, the research was done in PubMed and the keywords used were "music" and "autism". It resulted in 79 articles, of which 15 were unavailable, 18 excluded by title, 6 excluded by abstract and 7 excluded by content, leaving 33 articles.

While the mechanisms behind it are not yet fully understood, it is clear that music can have a powerful influence on individuals with autism and can be an effective tool for improving their quality of life because it helps to improve communication, social interaction, and emotional expression. Consequently, music therapy (MT) became a commonly used intervention to target those core difficulties in autism.

Music therapists can use instruments, such as drums or xylophones, to help individuals with autism communicate their emotions and feelings and this can be especially helpful for individuals who struggle with verbal communication. Another way that music can benefit individuals with autism is by providing a structured and predictable environment, which can help to reduce anxiety and improve their ability to focus. MT can be incorporated into the lives of individuals with autism. For example, music can be used as a teaching tool to help individuals learn new concepts in a passive way and it can also be used as a tool for self-expression, allowing individuals with autism to express themselves in ways that they may not be able to do verbally, in active way.

From a neurophysiological standpoint, music can serve as a valuable tool for promoting cortical plasticity in individuals with ASD. This is because music can rewire sensorimotor circuits in the brain, leading to improvements in motor control and repetitive behaviours. Furthermore, music has the potential to strengthen the connections between various regions of the brain that are involved in sensory processing and emotional regulation, such as the amygdala-hippocampal complex, cerebellum, basal ganglia, and anterior and posterior cingulate regions, as well as the mirror neuron system (MNS) and anterior insula.

Despite advances in understanding the underlying causes of ASD, there are still no effective treatments that can address its core deficits and normalize its pathophysiology or prevent its expression. Therefore, the development of novel disease-modifying therapies that can target these deficits may ultimately prove to be the most effective way to improve outcomes for individuals with ASD.

2 Objectives

To begin with, it is crucial to comprehend the diagnosis and prognosis of autism, and how it affects socialization, communication and behaviour of an individual with autism. After that, the aim is to investigate how music can be beneficial in addressing these impairments. This involves examining the impact of various music approaches, such as listening to music, interactive or educational music therapy, improvisational music therapy, or a combination of methods. It is important to evaluate the outcomes of each approach in addressing specific symptoms or groups of symptoms across the wide spectrum of this disorder.

As additional goals, this work aims to provide a critical evaluation of the existing literature on music as a therapy and autism, highlighting the strengths and limitations of the research conducted in this area, the main purpose being to make recommendations for future research on the use of MT for individuals with ASD, including the need for further randomized controlled trials and studies that investigate the underlying mechanisms of the therapeutic effects. Lastly, it aims to point out the importance of raising awareness of the potential of MT as a therapeutic intervention for individuals with ASD, and to encourage its integration into mainstream treatments for ASD.

The purpose of this dissertation is to prove that music can be therapeutic for people with autism, not just to soften the symptoms but also to improve the quality of their daily life. Although it´s still not a scientifically validated as treatment, it is important to acknowledge that this type of therapy can be a potential and crucial intervention for autistic individuals, and that is the main reason why I choose to discuss this issue.

4. Results and discussion

4.1. Autism Spectrum Disorder and Neurophysiologic correlations

4.1.1. Historical Context

Autism comes from the Greek word "autós" which means "self". Originally, in 1908, a Swiss psychiatrist named Eugen Bleuler used this term to describe a disconnection from reality in people with schizophrenia (1). However, in 1943, Leo Kanner redefined the term to describe a set of symptoms seen in children who have difficulty communicating and interacting with others, as well as displaying repetitive behaviours and a loss of interest in social activities (1). These symptoms are not associated with schizophrenia or any other known psychiatric condition (1).

A year later, Hans Asperger identified children with social isolation who lacked the linguistic abnormalities typical of autistic children and this led to the diagnosis of a new autistic-like disorder, which became to be known as Asperger's Syndrome (AS) (1). In the same year, the fourth edition of the American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) included five Pervasive Developmental Disorders (PDDs): autistic disorder, Asperger's syndrome, pervasive developmental disorder-not otherwise specified (PDD-NOS), Rett's disorder and child disintegrative disorder (1).

Children diagnosed with these disorders typically showed deficits in three domains: social interaction, communication, and repetitive/restricted behaviours, and there could be rather large variations in symptom severity across different disorders, predominantly in the development of spoken language (1). For instance, a patient with AS may have had no significant language delay whereas a patient with PDD-NOS or autism may have suffered from severe impairment in the development of spoken language (1). The wide variations in the severity of symptoms both within and across the group of disorders complicated the ability to effectively discern one disorder from the other (1).

Looking back, the 3TH edition of Diagnostic and Statistical Manual of Mental Disorders (DSM-III) conceptualization of autism, and the theories of autism that followed its introduction, were shaped by converging developments in psychology and psychiatry in the

1970s (2). These involved the collapse of psychoanalysis' cultural hegemony in the field, a growing emphasis on empirical data as the platform for clinical decision-making, and a shift in focus from individual cases to group and epidemiological studies as the foundations for understanding the nature of psychiatric conditions and psychological phenomena (2).Against this background, the rising influence of cognitive science on psychological disciplines in the 1980s paved the way for the increase of cognitive accounts of autism (2).
Consequently, although Kanner described ASD for the first time in 1943 and Asperger reported about autistic psychopathy in 1944, until 1980's it was treated as a psychiatric disorder and children were misdiagnosed as being schizophrenic (2,3). In that year, seeking to eliminate some of this misperception, the 5th edition of Diagnostic and Statistical Manual of Mental Disorders (DSM-V) shifted from grouping the disorders as separate diagnoses under the umbrella of PDDs to conceptualizing them as all members of the broader category of known as Autism Spectrum Disorder (1). It was not until 1980 that autism was added to this manual and eventually the diagnosis was replaced by its contemporary definition as a complex neurobiological pervasive developing disorder (4). The NDD section of the DSM-V includes autism spectrum disorder, intellectual disability, attention deficit disorder with or without hyperactivity, developmental coordination disorders, communication disorders, including language, phonological, and pragmatic social communication disorders, and stuttering, and specific learning disabilities, characterized by persistent difficulties in learning the fundamental academic skills of reading, writing or mathematics (5).

4.1.2. Prevalence, Risk factors and comorbid disorders

In the last two decades, there has been a continuous increase in the prevalence of ASD (1,6,7). According to The National Health Center for Health Statistics in 2016, the latest reported rate has reached a high level, with ASD being identified in as many as 1 in 36 children. This prevalence ratio is believed to be consistent across different racial, ethnic or socioeconomic backgrounds, but there are gender variations, with a higher prevalence among males (1,6,7). The increase in ASD prevalence may be due to several factors, such as better diagnostic criteria and more accurate neuropsychological scales, increased awareness and access to services, broader diagnostic criteria, environmental toxins, poor nutrition, pregnancy stress, maternal obesity, and an increase in gametic mutations resulting from pregnancies to older parents (1,6,7).

Genetics plays a prominent role in ASD (1,6). Twin and family studies suggest that hereditary factors contribute to the development of ASD, with high convergence rates in monozygotic twins, where it is likely that the most cases arise on the basis of multiple susceptibility genes, with influence from environmental or other factors (1,6). On the other hand, family studies indicate that the rate of autism in siblings of autistic individuals is about 2.2%, and the sibling recurrence rate for all PDDs is 5% to 6%, significantly greater than that of the general population (1,6).

These disorders are more frequently expressed in patients with chromosomal abnormalities such as Down's syndrome and fragile X syndrome, however a minority of cases of autism can be attributed to genetic disorders (1). In a study from Portugal, one group reported a relatively high prevalence of autism in the Azores, also with an unexpectedly high rate of mitochondrial–respiratory chain disorders (8). The presence of infantile spasms in infants added to the prevalence of autistic patients of whom 30% fit the definition of autism (8). Birth order was relevant according to another group, showing that firstborns had significantly worse scores for repetitive behaviour and, therefore, were possible candidates for autism (8).

Furthermore, parental history of psychiatric disorders, premature birth, gestational diabetes and fetal exposure to psychotropic drugs, including antidepressants, or insecticides have both been linked to a higher risk of developing ASD (1,7). Nonetheless, additional clinical studies are still needed to validate whether there is definitive increased risk of ASD, particularly in children born to women diagnosed with depression who are receiving either no treatment or antidepressant treatment during pregnancy, and to also correlate this risk with medication effect, antidepressant types and dosages during pregnancy (1,7). Additionally, the influence of environmental interacting with genetics might also be considered a risk for ASD development (1,6). Other possible aetiologies can be systemic disorders, like autonomic disorder, growth and hormonal factors, electrolyte disorders, oxidative stress, high testosterone level, among others (6,8).

As many as 75% of children with ASD are also affected by other medical, psychiatric, or neurological disorders that can result in additional physical and/or mental impairment (6,8). In addition, there may be comorbid phenotypic characteristics, such as skin and food allergies, and variations in the digestive microbiome that may either cause or be a part of the syndrome, so this can make diagnosis and treatment more difficult, increase the cost of treatment, and create additional demands on the families of those affected (1,2,7). To achieve the best outcomes for individuals, evidence-based practices and strategies that are tailored to the individual's needs should be used, taking into account the economic factors and level of diagnosis (9). There are more than 16 different disorders or conditions that are often associated with ASD, including ADHD, anxiety, bipolar disorder, inflammatory bowel disease, epilepsy, fragile X-syndrome, gender dysphoria, intellectual disability, neuroinflammation and immune disorders, non-verbal learning disorder, OCD, schizophrenia, sensory problems, sleep disorders, Tuberous sclerosis, and Tourette syndrome and tic disorder (1,8). It is essential to recognize the high rate of comorbid disorders associated with ASD and identify or eliminate them appropriately to guide accurate diagnosis and treatment and improve the clinical outcomes and prognosis of individuals with ASD (1,8).

4.1.3. Diagnosis and Prognosis

Autism Spectrum Disorder (ASD) is a complex neurobiological condition that exhibits a diverse range of characteristics and one-quarter of children with ASD may exhibit developmental regression, which involves losing skills they had previously acquired (4,6,10). Symptoms of ASD are generally more apparent and easier to identify in children between two to three years of age (5,6). The diagnostic criteria for ASD are outlined in the International Classification of Diseases (ICD-11) and Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-V) (6,10). The criteria consist of three core elements: at least two qualitative impairments in social interaction, at least one qualitative impairment in communication, and at least one pattern of restricted, repetitive, and stereotyped behavior, interests, or activities (6,10).

Table 1 - Impairments of the three core elements in ASD diagnosis, adapted from (10,11)

Social Interaction	• marked impairment in the use of multiple nonverbal behaviours such as eye-to-eye gaze, facial expression, body postures, and gestures to regulate social interaction; • failure to develop peer relationships appropriate to developmental level; • a lack of spontaneous seeking to share enjoyment, interests, or achievements with other people; • a lack of social or emotional reciprocity.
Communication	• delay in, or total lack of, the development of spoken language (not accompanied by an attempt to compensate through alternative modes of communication such as gesture or mime); • in individuals with adequate speech, marked impairment in the ability to initiate or sustain a conversation with others; • stereotyped and repetitive use of language or idiosyncratic language; • lack of varied, spontaneous make-believe play or social imitative play appropriate to developmental level.
Repetitive and stereotyped patterns	• encompassing preoccupation with one or more stereotyped and restricted patterns of interest that is abnormal either in intensity or focus; • apparently inflexible adherence to specific, nonfunctional routines or rituals; • stereotyped and repetitive motor mannerisms; • persistent preoccupation with parts of objects.

Pervasive behaviours, such as developing rigid routines, are characteristic of individuals with ASD, so when there is a change in their routines, a significant stress and aggression begins to appear (11,12). One of most common mental health challenge for autistic individuals is anxiety, which may be related to a fear of loud sounds or to inanimate objects, and perhaps even related to atypical sensory experiences in autistic individuals (11,13). Many studies implicate excessive concern in autism regarding change and excessive rigidity about things such as foods, rituals, and clothing (13). Herein, there is three specific processes associated with autism and of potential relevance for anxiety: differences in predictive processing, intolerance of uncertainty, and what is commonly referred to as black and white thinking (13). While predictive processing is arguably a biological mechanism, intolerance of uncertainty and black and white thinking are psychological phenomena rooted in conscious and unconscious cognitive processing (13). It has been proposed that the autistic preference for sameness may arise from the anxiety caused by a world in which unpredictability is elevated (11,13). Reduced predictability of others and the environment may lead autistic individuals to strive for sameness as a way of ensuring maximum predictability (13). An insistence on sameness therefore goes hand in hand with the concept of intolerance of uncertainty (13). The key to understanding different presentations of anxiety in autism may lie in understanding autism-specific cognitive differences (13). There may be important differences in neurobiological, emotional, and cognitive responses to stressors for autistic people, which warrant tailored anxiety models, assessments, and interventions (11,13).

People with autistic spectrum disorder also present with a pervasive inability to 'mind-read', where a lack of perception and understanding of other people's feelings, beliefs or emotions results in a consequential inability to respond appropriately (10,14,15). This generates a severe impact on social skills and interactions, so the communication impairment in autism is believed to reflect a lack of understanding of the mind (1,14,15). There are significant limitations in the development of verbal language and conventional forms of non-verbal communication such as eye-contact, gesture and body language, with a correspondingly limited development of communicative skills (8,16). In this scope, the 'theory of mind', first described by Baron-Cohen in 1985, is the fundamental ability to understand actions and intentions of others, and to communicate them effectively, beginning in infancy toward the end of the first year of life, but in individuals with autism, deficits in this capacity have been linked to both impairments in executive functioning and communication difficulties (8,14,15). This inability to understand others intentions and behaviours may help to explain why language is delayed in children with this disorder, and why a significant proportion of them never acquire language at all (14,15).

Children with autism tend to have difficulty sharing their experiences with others and may avoid interacting with multiple social partners, even with guidance (14). Reduced attention to emotional cues may contribute to negative peer interactions and difficulty resolving conflicts with others, along with deficits in emotion processing that can impact social understanding and reciprocity, leading to less positive emotions displayed towards social partners and more negative affective exchanges (8,14). Additionally, children with autism may show reduced interest in faces and social referencing, which is the tendency to look to significant others in ambiguous situations that typically developing children exhibit (14).

In some individuals with high functioning ASD, symptoms may go unrecognized in early life, and the individual may be regarded as rigid, complicated, or odd because of their poor social competence (17). Such situations can lead to chronic interpersonal crisis, anxiety, social withdrawal, and depression in later life, because, in fact, these undesirable adulthood outcomes are due to the problems associated with ASD in childhood (17). Consequently, children with autism still demonstrate a need for structure and a systematic approach to promote appropriate and meaningful interpersonal responses (16). It is true that attachment behaviours are probably one of the earliest markers of social and emotional bonding, and studies have shown that children with autism are able to demonstrate secure attachments to their parents and carers (11,18). Nevertheless, while it is clear that a diagnosis of autism does not preclude the possibility of forming deep and meaningful bonds with others, difficulties in interpreting social–emotional cues are much in evidence, and the extent that these difficulties generalize to other types of emotion-invoking phenomena is an important question (18).

Besides poor joint attention, the communication deficits in autism may be related to imitation difficulties (15). Imitation involves translating another person's action into one's own, and is also considered to be a precursor of language development (15). Numerous studies have reported imitation deficits in autism and more recent evidence has provided further support for this claim (15). For example, Vanvuchelen et al. found that individuals with autism showed impaired performance in both gestural imitation and general motor skills, suggesting that their imitation deficits may be part of a broader perceptual motor problem (15). So, imitation deficits in autism are associated with problems both in comparing self with others and in motor planning (15).

As a spectrum, the clinical picture flows through different levels of ability, from profound learning disability to a spiky cognitive profile where superior skills are present in some areas of functioning. About 44% of persons with ASD have average intellectual ability, and about 83% of persons have co-occurring developmental, neurological, genetic, or chromosomal disabilities (10). Healthcare and social care for people with ASD is frequently complex, since they are more likely to have mental health comorbidities and suicidal ideation (19). The diagnosis of autism is a difficult task due to the availability of multiple clinical techniques, which typically require short-term observation and evaluation by licensed healthcare professionals (1,5). The symptoms of autism overlap with those of other psychiatric disorders, making it crucial to use appropriate instruments and scales to ensure accurate diagnosis, so a proper diagnosis can lead to improved clinical management of patients with autism from early childhood through adulthood (1,5).

Assessments need to be multidisciplinary and developmental, and early detection is determinant, as well as therapeutic interventions need to be personalized, focusing on the specific clinical features presented by each patient (6,19). Assessment instruments include parent/caregiver interviews, patient interviews, direct observation of patients, and detailed clinical assessments that encompass a thorough review of family history for ASD or other neurodevelopmental disorders (1,6). The scales that are widely used to diagnose are the following: autism diagnostic interview-revised; autism diagnostic observation schedule; developmental, dimensional and diagnostic interview; the childhood autism rating scale

(CARS); the autism spectrum disorder-observation for children; the autism diagnostic interview-revised; the Asperger syndrome diagnostic interview; the diagnostic interview for social and communication disorders; autism spectrum disorder scale for intellectually disabled adults (1,5). Highlighted, CARS is designed as a clinical rating scale for the trained clinician to rate items indicative of ASD after direct observation of the child. The form is used with individuals of all ages and not only in clinical and research settings, but also on therapeutic contexts (1,5).

There have been a few reviews on screening methods that have addressed common criterion, such as the number of items included in each screening test, time taken to complete the test, age categories involved, and performance, in terms of sensitivity, predictive accuracy, and specificity (5,11). Consequently, many children who were previously diagnosed with other disabilities, like emotional disturbance or mental retardation, are now more accurately diagnosed with autism due to improved diagnostic procedures and increased awareness (20). However, existing reviews have failed to critically analyse vital aspects related to ASD screening, including the tool's accessibility, comprehensibility, popularity, and efficiency among others (5). More importantly, none of the reviews emphasize the importance of the DSM-V criteria for evaluating the reliability of screening (5).

The prognosis for individuals with ASD is generally unfavourable, with only 25% of affected children and adults showing fair outcomes (6,12). Although approximately 15% of adults with autism can live independently, while another 15% to 20% can live alone with community support, most adults with autism continue to rely on their families or professional caregivers and may require lifelong full-time care due to difficulties with education, employment, independent living, and relationships (6,12).

Verbal and overall cognitive capacity seem the most important predictors of ability to live independently as an adult (6). If a child remains nonverbal by the age of five or six, the prognosis for social skills and expressive language has traditionally been thought to be poor (15). However, there is evidence suggesting that the acquisition of language after this critical period in autism is also possible (15). One of the strongest predictors for subsequent language acquisition and expressive language abilities was responsiveness to bids for joint attention at initial assessment (15). This finding highlights the importance of joint attention in predicting the language and communication deficits that are the hallmarks of autism (15).

4.1.4. Neurophysiology

There are several possible explanations for the structural abnormalities found in the brains of people with neurodevelopmental disorders (NDDs) (21,22). These may include factors that affect the brain before and after birth, such as exposure to certain risks during pregnancy or a lack of opportunities to use certain parts of the brain during development, leading to cognitive deficits that persist into adulthood, requiring ongoing support (21,22). Brain imaging studies have shown differences in the structure, function, and connections of various regions of the brain, including those important for language, working memory, executive functioning, and social skills (21–23). These differences are thought to result from altered brain maturation and early development (17).

4.1.4.1. Mirror Neuron System

The discovery of mirror neurons provided support for the involvement of the motor system in auditory speech perception (15). The shared representations of observed and executed actions in these neurons may serve as a foundation for our capacity to understand the experiences of other people, which is crucial to effective communication and social interaction (15). An intact MNS might underlie normal language functions in humans, and language comprehension may be achieved through action understanding and mental simulations of sensory-motor structures (15).

Evidence for the involvement of the motor areas in speech perception comes from neuroimaging studies with normally developing individuals, and it revealed that when participants read sentences containing motor words that were associated with the hand, leg, or head, the regions in the sensorimotor cortex that would normally be involved in the execution of that action became activated (15). Similarly, listening to speech sounds activated speech production motor areas, and both seeing and listening to speech activated regions of the putative MNS, specifically, the superior temporal sulcus and inferior frontal gyrus (15). Furthermore, transcranial magnetic stimulation studies showed an increase in motor-evoked potentials of the tongue when participants listened to speech, and that the excitability of motor regions underlying speech production correlated with activity in Broca's area (15). The MNS was first discovered by recordings in area F5 of the macaque, following observation that a specific set of neurons in the ventral premotor cortex fired in response to both observed and performed action (15). Since then, there has been increasing evidence to suggest that a comparable system exists in the homologous region of the human brain, namely Brodmann area 44 (Broca's area), an area of the inferior frontal cortex that has been strongly linked with language (15). Other areas such as the inferior parietal lobule and the superior temporal sulcus are also believed to contain mirror neurons (15).

Mirror neurons are involved not only in the perception and comprehension of motor actions in humans, but also in higher-order cognitive processes such as imitation and language, which are often impaired in individuals with autism (15). Over the past decade, some researchers have proposed that mirror neuron dysfunction might underlie the behavioural manifestations presented in autism (15). For example, Nishitani et al. used magnetoencephalography and electromyograms to measure brain activity and lip movement when individuals with Asperger's syndrome were asked to imitate orofacial gestures (15). Compared to controls, the ASD group had electromyograms that lasted almost twice as long (15). Moreover, the ASD group showed weaker activations in Broca's area, which was delayed by 45–60 ms. Similarly, when imitating facial expressions inside the magnetic resonance imaging (MRI) scanner, children with autism showed decreased activity in Broca's area relative to controls (15). Although behavioural performance between these two groups did not differ, Broca's area activity in the autism group correlated with severity of autism as measured by the social subscales of standardized tests (15).

4.1.4.2. Insula

The insula is an area associated with awareness and cognitive processing of emotional states (24). The main focus on this section will be the anterior insula (AI), which is involved in affective processes and plays a major role in social cognition, especially perceiving, imitating, and empathizing with the emotional expression of another individual (24,25). These processes have been hypothesized to rely on the MNS, where the AI plays a crucial role by integrating action representation information from the superior temporal and inferior frontal nodes with emotional processing information from limbic areas (24,25).

Action representation and emotional processing are key components of emotional facial expression recognition due to dynamic physical changes of the face across different expressions and the emotional information conveyed through each specific expression (25). In turn, perceiving and understanding emotional facial expressions is one of the first components of empathy, as one must understand how someone else is feeling by observation of their facial expression to empathize with those feelings (25). Evidence from brain network analyses suggests that the anterior insula can be considered as part of a salience network (SN), which serves to integrate sensory data with visceral, autonomic, and hedonic information, making it a region that is critically involved in social–emotional processing (14).

In addition, AI also plays a key role in bottom-up attentional processes and mediating switching between internally and externally-oriented cognitive processes (25). In the context of attention and network switching, the AI is a key node of the SN along with the anterior cingulate cortex (25). In the context of the SN, the AI not only orients attention towards important stimuli, but also interacts with other brain regions to engage networks related to top-down attention and working memory to further process relevant salient stimuli while disengaging networks (25). The AI acting as part of the SN provides a high-level switching mechanism that is relevant for both social and non-social cognitive processes (25). Social cognition can involve aspects of face perception, emotional expression recognition and empathy, while non-social cognition can include processes such as executive function and language, and both the social difficulties and non-social difficulties characterize ASD (25).

Recent work in network neuroscience has carved out a unique role for the anterior insular cortex of the human brain in orchestrating large-scale brain network dynamics (25). Nearly a decade ago, it was proposed that this unique function of the AI as a focal point coordinating brain network dynamics rendered this brain region a prime candidate for investigation in autism ASD, which is marked by deficits across multiple functional domains (25). Since then, the insula may be a primary locus of dysfunction in autism, and it may actually be a common transdiagnostic characteristic, present in schizophrenia, bipolar disorder and depression, for instance (25). When we speak in structural terms, there is a general lack of structural AI abnormalities in individuals with ASD in contrast to the findings of atypical AI function in ASD and one explanation for that is that the size of a brain structure is not always related to the number of neurons residing within that structure (25).

A meta-analysis including data from participants across a wide age range showed that individuals with ASD generally exhibit right AI hypoactivation during face perception, voice perception, and imitation tasks, and it may depend on the type of pain, physical or social, the type of social norms, like rule violations or exclusion, and what kind of affective regulation and emotion (25). For example, adults with ASD show no difference in pupil dilation, behavioural response, or brain activity when viewing images of physical pain, like cutting your finger, but show reduced pupil dilation and behavioural responses in addition to right AI hypoactivity when viewing images of social pain, like an embarrassing situation (25). In children with ASD, there is AI hyperactivity in response to playing a video game promoting rule violation, but right AI hypoactivity in response to social exclusion (25).

These social paradigms can be related to MNS dysfunction, because, as mentioned before, it is involved in many aspects of social cognition related to processing of emotional facial expressions and empathizing (25). A second explanation is that AI dysfunction in social processing in ASD may be related to dysfunction of the broader SN, linked to the fact that they do not find social stimuli salient and meaningful (25). On the other hand, AI dysfunction in ASD during social stimulus processing may also be linked to a dysfunctional switching process relying on the AI (25). It may be the case that even if individuals with ASD do find social stimuli salient, further downstream processing is not effectively carried out due to atypical insula activity that interferes with initiating and suppressing networks important for higher-order processing of stimuli (25).

In terms of non-social cognition, AI dysfunction is related to effects mediated by the SN, affecting how individuals with ASD orient towards salient information, or how central executive network activation is initiated, thereby interfering with executive functions broadly (25). As attention and network switching processes are critical for the flexible cognition required for most executive function tasks, AI dysfunction may contribute to the poor executive function performance often observed in individuals with ASD (25). Thus, even if stimuli are recognized as salient, there may be difficulties in communicating relevant information to other networks involved in further processing of the salient information (25).

4.1.4.3. Cortical Connectivity and Sensory Integration

ASD is often viewed as a disorder in which the brain has trouble forming long distance connections between different regions, leading to overcompensation in short distance connections (1). This can result in enhanced attention to simple stimuli but difficulty integrating them into a more complex understanding (1). Recent research has found reduced activation and communication efficiency in certain brain networks related to social understanding in adolescents with ASD, suggesting that overconnectivity may not always lead to better performance (1). Additionally, subcortical connectivity dysfunction may play a role in behavioural issues related to poor sensory regulation (1). These connectivity issues may impact the ability to understand and react to social cues, and may represent the brain's attempt to compensate for difficulties in processing input from multiple senses (1).

Neuroanatomical evidence on how subcortical neural systems form in the human embryo brain, and the function of the same systems in directing both formation of the neocortex in the fetus and development and function of psychological functions after birth, support the view that serious difficulties with intelligent learning in early childhood are caused by gene faults or toxins that damage intrinsic motivation/emotion systems at a very early age (26). Early task-based MRI investigations showed decreased functional connections between frontal-anterior and posterior brain areas, leading to the hypothesis that ASD is characterized by hypoconnectivity (25). Atypical functional connections appear to be most common between the AI and SN nodes that include the amygdala, between the AI and prefrontal brain areas related to the central executive network, and between the AI and default mode network nodes that include temporal areas and the thalamus (25).

There has been a recent movement in the field of neuroimaging research to provide a more comprehensive picture of atypical brain structure and function by paying more attention to developmental stage (25). It has been proposed that individuals with ASD can developmentally shift from hyperconnectivity in childhood to hypoconnectivity in adolescence and adulthood and this shift may be supported, exacerbated, or interact with behavioural challenges that autistic individuals begin to experience in adolescence such as the formation of friendships or romantic relationships and also neural changes related to myelination and synaptic pruning (25). These major changes in behaviour and brain anatomy strongly indicate that researchers should take developmental stage into consideration in MRI studies of ASD (25).

Baum et al. suggested that the integration of sensory information is crucial for higher-order cognitive functions, and that deficits in multisensory integration are a fundamental aspect of ASD, rather than just one feature of the disorder (1). These deficits in multisensory processing affect the ability to form complex cognitive representations and metaphors, which are important for language comprehension and social interaction - two core symptoms of ASD (1). Additionally, individuals with ASD often have atypical sensory processing, such as heightened sensitivity to intense visual or auditory stimuli, and studies have found that individuals with autism tend to have enhanced processing of local or detailed visual features, with either diminished or intact processing of global features, in comparison to typically developing individuals (1,27).

4.2. Music and the impact on cerebral function

The arts encompass a wide range of outlets for creative expression and exploration (28). The ability to enjoy music is a universal human trait and we engage with it spontaneously and effortlessly (14,18). The motivations for listening to music are extremely diverse, and did not differ in appreciable ways from those of people without developmental disorders (14,18). Memories are triggered, emotions are awakened and social experiences are intensified when listen to music, enabling us to share thoughts and feelings (14,18). The fact those emotions can be communicated through music is one of the reasons people listen to it and find it rewarding and pleasant (24). Besides, music exists in all forms of society and has a universal and unique social and cultural role, connecting people with different perspectives and realities (21,23). There is also a personal aspect that music evokes and, throughout a lifetime, it can reinforce our sense of self, strengthening interpersonal bonds and identification with one's group (21).

Modern neuroscience has revealed that music is a highly complex and precisely organized stimulus that interacts with the human brain and modulates synaptic plasticity and neuronal learning/readjustment in the brain (29). For the human brain to process musical stimuli, a substantial proportion of the cortical mantle and several neural networks (29). Musical processing begins from the transduction of acoustic information via the outer and middle ear to the cochlea, where the vibration of musical sound is transformed into neural activity and transmitted to the auditory brainstem (21,29). The auditory brainstem processes the neural signals and sends them to the thalamus, which projects them into the auditory cortex (1,29). The auditory cortex extracts more specific acoustic information, such as pitch, chroma, timbre, intensity, and roughness (29). These components of music are processed by diverse brain areas linked together hierarchically, arousing associated memories along with emotional and behavioural responses (21,29).

Music's ability to modulate feelings and mood is well established: both experimentally and anecdotally (1). Both passive listening, and to a greater extent, active playing, have been shown to activate areas of the brain involved in cognitive, sensorimotor and perception-action mediation through increasing the oscillation synchrony between these various cortical areas and thereby promoting heightened sensory-integration (1). Both short and long-term music listening and music making engage multisensory and motor networks, induce changes within these networks and create connections between distant, but functionally related, brain regions with continued music exposure (1).

Music-making and listening are meaningful and enjoyable activities that invite social interaction and bonding (23). This social interaction is evident early in development, when infants are highly attuned to the fluctuations in pitch and rhythm of speech, called prosody, or song from a mother or primary caregiver (23). Early sensitivity to speech prosody suggests that humans are adapted to use the musicality of speech for bonding and communication prior to language development (23). Timing in mother–infant babble and preverbal engagement has been suggested as the foundation of human communication, and this type of interaction relies on shared or joint attention, where complex neuro-behavioural coordination provides the foundation for higher functions such as communication and social interaction .

In adolescence, music itself is more often used to bring people together and define group membership (23). In older age, the deterioration of physical and mental capabilities can restrict the capacity for social interaction (23). Studies have shown that the effects of social cohesion are particularly powerful when we sing in a group compared to when we engage in other group activities, such as craft or writing (23). When making music or moving together in a social context there is a release of neurohormones such as oxytocin, a neuropeptide released by the posterior pituitary gland, which is associated with social bonding and empathy and trust (16,23). Music is a complex experience that involves multiple senses, including sight, hearing, touch, and movement (12,15). When making or listening to music, the brain processes and integrates these sensory inputs to control and execute motor actions (12,15). Both passive listening and active music-making can activate certain areas of the brain, such as the superior temporal lobe and inferior frontal areas, which play a role in cognitive, sensory, and motor processing (12,15). This synchronization between different brain regions can enhance sensory integration and perception-action mediation (12,15).

Whether individually or collectively, music-induced emotions are associated with changes in the autonomic nervous system, such as fluctuations in heart rate, blood pressure, respiration, electromyogram signal, and electrodermal response (23,24). These responses often result in a sensation of goose-bumps or chills and positive emotional experiences tend to dominate, even when music is perceived to be sad or violent (23,24). At the neural level, MRI studies showed that musical chills are associated with activity in several regions including: the hypothalamus, which may point to pleasant music eliciting an autonomic response given its role in controlling heart rate and respiration; the nucleus accumbens (NA) and ventral tegmental area (VTA), which suggests occurrence of a reward response; and the left amygdala, which is associated with processing of music-evoked emotions along with the NA and hypothalamus (24). Using functional MRI, researchers have examined the neural correlates underlying emotional responses to music, and have found that listening to pleasurable music leads to an increase in the level of dopamine in the NA in the moments before the peak of an emotional response and increased opioid circulation and mu-opioid receptor expression (23). Such neurobiological effects are also observed for biologically rewarding stimuli such as food and drugs (23).

It is easy to understand that the engaging nature of music occurs on both neurological and psychological levels (23). The long-term effects of music engagement on the brain include neuroplastic changes associated with benefits to auditory and motor functions, and the differences are evident when we compare musicians and non-musicians for example (23). Young musicians have been shown to perform significantly better than non-musicians on various cognitive tasks including those assessing auditory, vocabulary, abstract reasoning, mathematical and motor functions (23). Also, compared to non-musicians or amateurs, professional musicians demonstrate changes in the volume and density of the motor cortex, arcuate fasciculus as well as the cerebellums, and the structural brain differences can even be specific to the instrument played (23). In addition, children who engage in long-term instrumental practice have larger corpus callosum as well as frontal, temporal and motor areas relative to controls (1).

Music is known to regulate arousal as well as attention in the brain and has the capacity to engage different areas in the brain, where perception and production of auditory rhythms involves the subcortical and cortical brain networks of the auditory cortex, basal ganglia, supplementary motor area, premotor cortices, and cerebellum (3). The architecture of the auditory system detects temporal patterns in auditory signals with great precision and speed (3). The whole brain responds to music and the pitch of the music is processed in the right temporal lobes which also governs speech, making it possible to use music to improve interpersonal communications (3). More specifically, for example, lesions of the cerebellum can impair the ability to learn music as affected patients have increased variability in motor timing, as well as decrements in discrimination of auditory intervals (30). Damage to the lateral cerebellar hemispheres caused increased variability in the timing component of the tapping task, while with damage to the medial region here was increased variability in the motor implementation component of the task (30). So there seem to be at least two separate neural networks involved in the processing of musical information, one related to the auditory component and one to the temporal variations, and lesions of the cerebellum will impair the function of the latter system (30).

Rhythm, the primary structural feature of music, denotes the division of time through distinct order (3). Similarly, in our human life, the natural and extemporaneous body movements are a demonstration of inner rhythm (3). In utero, a fetus's neural circuits and auditory memory are forming and at five months, it can feel the rhythm of the mother's heartbeat and respiration (3). After birth, during development, each child finds a particular motor rhythm which will endure consistently throughout life (3). Neurologically, Rhythm also incorporates sensory perception and motor entrainment, which results into complex cognitive functions and motor adaptations (3). Rhythmic synchronization may activate several cortical and sub-cortical regions involved in timing, including the cerebellum, basal ganglia, parietal cortex, prefrontal cortex, premotor cortex, and supplementary motor area (23). The synchronization of bodily movements to an external beat is an instinctive human action that is strongly associated with the process of neural entrainment and the repetitive neural firing that coincides with temporally predictable events such as a musical rhythm (23). This rhythmic neuronal firing can continue without any further input from the original rhythmic source, allowing individuals to predict or anticipate when the next event, like the next musical beat, will occur, providing a steady timing cue so that the brain can plan ahead (23).

With all of these positive effects of music in mental health, there is increasing recognition of the potential of music to improve psychological, motor and behavioural functions in people with neurological disorders, such as Parkinson's disease, dementia, schizophrenia, depression, substance use disorders, disordered sleep and of course ASD (23,29). It has been studied and proved that it can facilitate communication and emotional functions, and the influence of music in these individuals will be the main focus of the next chapters (23,29).

4.3. Music Therapy and applications

Throughout history and across cultures, there have been reports of music having healing effects, from biblical scenes of David playing the harp to the Gnaoua ritual in Maghreb (22). In the eighteenth century, Pinel advocated for the use of music as part of the moral treatment in psychiatry (22). Music has since remained a component of occupational therapy for patients receiving ambulatory care for chronic mental health conditions (22). It was only after World War II that music therapy became a structured psychotherapy in North America to treat veterans, due to its many different levels of structure, which provides the variability and flexibility needed to counteract the more rigid characteristics of the pathology (16,22).

The World Federation of Music Therapy defines it as the professional use of music and its elements as an intervention in medical, educational, and everyday environments with individuals, groups, families, or communities who seek to optimize their quality of life and improve their physical, social, communicative, emotional, intellectual, and spiritual health and wellbeing (17). Also, it is seen 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 (10,17). MT aims at maintaining, restoring and furthering physical, emotional and mental health and it is a conscious and planned intervention for many diagnostic groups, such as psychosocial and physiological diseases (31). It might be organized as self-help, individual, group-based, or peer-mediated therapies, and the purpose of this treatment is to transfer the skills developed in music-based experiences to other areas of life by developing cognitive, motor, emotional, social, sensory, and learning skills (17,32). The group-based MT aims mainly to use music relationships to encourage patients to develop social connections with others (17,32).

The efficacy of music-based interventions can be investigated on four levels of analysis: therapeutic contexts, active ingredients, neural mechanisms, and benefits (23). With respect to therapeutic contexts, music-based treatments are typically classified into individual or group therapies that can be administered in either passive, listening, or active, such as singing, drumming, clapping, dancing forms (23). Several researchers have reported that music-based interventions can trigger neural processes that result in measurable benefits, and those benefits may be classified into behavioural, cognitive, motor, and psychosocial domains (23).

Music therapy is recognized as a regulated health profession in some countries, including Austria and the United Kingdom, while efforts are being made to achieve government recognition in other parts of the world (31). Music therapists use personalized music-based interventions to improve social, communicative, motor/sensory, emotional, cognitive, and musical skills in individuals, in collaboration with families and treatment teams (9,31). These interventions can be provided in various settings, such as schools, homes, specialized clinics, and hospitals, and are tailored to the individual's preferences and abilities after an initial assessment (9). The treatment plan is designed to target areas of need, with the therapist adapting the protocols within different approaches to best meet the individual's needs, becoming important techniques like dialoguing, to disrupt rigid patterns of musical behaviour and play (9,16).

While music is easily accessible to a range of professionals, it must be noted that casual listening of music on mobile devices is not the same as MT that is guided or facilitated by music therapists (28). Music therapists are found in a range of settings, including hospitals, schools, and outpatient therapy nucleus, that often provide services to individuals with communication disorders (28). Studies frequently included a credentialed music therapist as the interventionist and included specific techniques, but this doesn´t happen in all of the cases, which is a disadvantage for outcomes credibility (28).

Musical interaction, especially improvisation, is often compared to a type of language that does not require words. It allows people who struggle with verbal communication to express themselves emotionally and connect with others on a deeper level (10). In music therapy, listening to music is also interactive and involves selecting music that holds personal significance, and reflecting on personal issues or memories that come up while listening (10).

Musical training involves the cortical areas of movement such as, the precentral gyrus, the supplementary motor area, the cerebellum, auditory, occipital, sensory, frontal brain areas and the anterior corpus callosum and improves cortical plasticity and promotes structural and functional connectivity in the brain (3). Several researchers have also speculated on the neural mechanisms underlying improvements in speech, motor, and memory functions following music-based interventions (23). Some of the proposed mechanisms of action responsible for inducing therapeutic change include priming neural networks that link music with non-music functions such as autobiographical memory and language, the activation of the MNS, auditory motor coupling, facilitation of motivation and reward, and neuroplasticity (23).

What is unique to music is that it employs a comparatively large number of therapeutic capacities within a single package that is at once convenient, enjoyable, and universally accessible, showing to be superior to similar forms of therapy where music was not used, and this may be indicative of a specificity of the effect of music within MT (10,23). Across populations, it is well established that music can be used to alleviate pain, anxiety, agitation, and depression, as well as ease some of the main symptoms of disorders mentioned before (23). Although the therapeutic use of music is found in many helping professions, the mechanisms behind its healing effect remains unclear, and more research needs to be done, especially is ASD (29).

4.4. Music Therapy applied to Autism Spectrum Disorder

As mentioned earlier, individuals with ASD face difficulties with communication, behavior, and social interaction, and when it comes to treatment there are numerous pharmacological and non-pharmacological interventions, based on various approaches, available for treatment (1,10,11). However, in this context, the focus will be on MT because it has shown promise in improving social interaction and verbal communication, and it enables individuals to express their feelings, which addresses some of the core challenges faced by people with ASD (1,11). Clinicians and researchers have explored the effects of MT from different angles, such as behavioral, relationship-centered, applied behavior analysis-based, family-centered, improvisational, and neurological, to enhance social skills and communication (9). Thus, there are various approaches and interventions available within MT to target social skills (9).

Music-based training significantly improves verbal and gestural communication abilities compared to placebo therapy in individuals with ASD (3). In many countries, using music as a therapy has been practiced as a useful intervention to improve social interaction, verbal communication and socio emotional reciprocity (3). In 2011, Quintin et al. have further claimed that the ability of ASD individuals to recognize the emotions behind music were similar to that of other individuals, making music a potential therapeutic strategy (3).

4.4.1. Historical Context

The formation of the National Association for MT in 1950 marked a significant moment in the development of the music therapy profession, which later became known as the British Society for Music Therapy (4). Early literature on the use of music with children with autism highlighted their exceptional musical abilities and attraction to music (4). Moreover, at this time, music therapists used various techniques such as adapted music education, folk dancing, singing groups, and rhythm activities to help individuals achieve goals related to self-expression, socialization, rehabilitation, psychological enrichment, and recreation, in both individual and group settings (4).

Paul Nordoff and Clive Robbins developed an innovative approach to music therapy for children with autism during the 1950s, based on their vast experience as musicians (4). They believed that music offered a safe and comfortable way for children with autism to engage with others and the world around them, particularly through improvisational music-making (4). Their groundbreaking work led to the establishment of the Nordoff-Robbins Charity Institution of Music Therapy in 1976, which is now the largest music therapy organization in the United Kingdom (4).

To address autistic children's attention in establishing communication, many musicians including Julliette Alvin and Pablo Goldstein used speech dynamics, rhythm, instruments, and movement (4). However, the lack of research evidence in therapeutic approaches for children with disabilities, including autism, led to the emergence of music therapists in the early 1970s who worked towards a more clearly defined approach (4). When Nordoff and Robbins published their book Creative Music Therapy, the improvisational movement gained international momentum by introducing a theoretical foundation of improvisational approach where every child has a unique, innate capacity for musical response, expression, and engagement (4). In 1985, music therapists formed the World Federation of Music Therapy, providing international music therapists with the momentum to make a more prominent impact in the research literature with children with autism (4). As a result, new publication venues and increased international unity led to the appearance of articles regarding MT treatment for children with autism (4).

From 1982 to 1989, the focus was on the sensory sensitivities of children with autism in MT, in which the timbre, the vibrations, and the resonance of instruments were elements that influenced the sensory awareness of music and the following behavioural response of children with autism (4). Furthermore, there was a strong implementation of adapted music education techniques such as folk dancing, rhythm band, music games and instrument instruction, associated with contingent reinforcement and behaviour (4). Most music therapists addressed communication and motor skills, behaviour, cognition, emotional and psychological concerns, musical ability, and sensory sensitivities (4). This expansive list of goal areas reflects the trial and error of this period (4). In 1988, the American Music Therapy Association published a comprehensive compilation of music research reviews documenting the effectiveness of music-based practices. Research from decades past provides an important historical perspective, and articles focusing on specific disabilities contribute to data bases for MT and music education practices (20).

In the 90´s, music therapists began more focused practice with children with autism (4). They aligned goals with diagnostic criteria as autism became a well-established term (4). Although music therapists strived to improve their approach with this population, numerous criticisms of efficacy persisted about their role, due to the lack of strong evidence-based support (4).

In 1997, Griggs-Drane and Wheeler explained how non-music therapy educational techniques could be useful in music therapy for children with autism (4). They described components of the TEACCH program, such as individualized activity schedules and the use of preferred and non-preferred activities, which could decrease problematic behavior during therapy sessions (4). In 1998, Heaton et al. taught children with ASD to associate syllables or musical notes with pictures of animals, and found that the group with ASD showed more accurate memory for pitches one week later compared to a group with typical development (4,24). In the same year, Starr and Zenker summarized the effectiveness of different approaches, including improvisational techniques, structured music therapy, and hybrid approaches, for children with ASD (4,24).

At the very begging of the 21st century, Thaut begins by investigating a specific physiological, neurological, or psychological response to music and then connects this response with an analogous non-musical response (4). Once the researcher has determined if the musical responses can be generalized to a non-music setting, the effects of music on behaviour are systematically studied to develop an empirically supported hypothesis (4). Finally, the researcher studies a specific intervention or treatment protocol that is based on the developed hypothesis (4). Thaut developed the Transformational Design Model (TDM), the rational-scientific mediating model, a systematic method of conducting high quality research to establish evidence-based interventions and theoretical foundations (4). The TDM, an interdisciplinary approach for providing evidence-based treatment, aims to dispel the use of activity-based, non-goal driven treatment (4). Logic, creativity and strong functional musicianship, clinical wisdom, and evidence from research are used to transform these non-musical exercises into MT applications, creating a holistic plan for generalizing skills from therapy to reality (4).

In recent years, music therapists have continued to use many techniques from the previous 40 years, such as singing, music games, and improvisation (4). They have also expanded their repertoire to include family-based treatment, prescriptive songs, and providing clients and caregivers with tools for use outside of music therapy (4). However, the research base from 1990 to 2009 primarily consisted of case studies, and many articles did not provide enough detail about the techniques used for replication in practice or future research (4). Recent studies have included low-quality randomized controlled trials, systematic reviews of comparative studies, and case studies with quantitative analysis (4). In response to criticism from within the field and from professionals in other fields, music therapists in the past two decades have aimed to produce stronger research evidence (4).

In 2004, Gold et al conducted the first meta-analysis on the effectiveness of music therapy for children and adolescents with psychopathology, and found that it had a medium to large effect on this population (16). However, only one study included in this analysis specifically examined the effects of music therapy on children with ASD (16). Two systematic reviews have since been conducted that focused specifically on ASD, but their results conflict with each other (16). The first review by Whipple in 2004 included various types of interventions involving music and found a large, significant, and consistent effect size (16). Nevertheless, the studies were so diverse that it was hard to draw any conclusions about the effectiveness of music therapy specifically, and significant design features of the studies were not made clear (16).

Despite a lack of research evidence and compelling rationales to support the majority of intervention techniques used in music therapy with children with autism, many music therapists have continued to use similar techniques (4). However, a significant issue in the past 59 years of MT practice with this population is the lack of detail in intervention reporting (4). To ensure successful clinical practice, music therapists must provide enough information in published research, learn from other fields, recruit larger sample sizes, and increase the number of well-designed comparative studies (4). The ultimate purpose of MT research is to benefit the client receiving treatment, and improving intervention reporting and research quality is crucial in achieving this goal (4).

4.4.2. Interaction of autistic individuals with music

Autism is characterized by both challenges and strengths, and there is growing evidence that music perception and ability are one of the relative strengths of people with ASD, taking into account their challenges (13,24). In the first report of autism, Kanner described the exceptional musical skills of several individuals, raising intriguing questions about musical interests in autistic children without savant talent (15,18). Talented savants are those persons in whom musical, artistic, mathematical or other special skills are more prominent and highly honed, usually within an area of single expertise (15,18). Nowadays, it is true that patients diagnosed with autism generally show a preserved, and even heightened, sense of musicality that extends into adulthood, with an ability to interpret and respond to the emotions conveyed in song or music even when unable to do so in speech (1).

From a young age, infants are responsive to the rhythmic and melodic aspects of language and its emotional content, indicating that we have an innate ability to engage in musical communication (10). Research has shown that individuals with ASD display a heightened interest in music and possess enhanced musical abilities, with neurological responses to music similar to those of professional musicians (9,10). This makes music an effective tool for nonverbal social interaction for individuals with ASD, both children and adults (9,10).

In a recent observational pilot study, it was tested patterns of attention in response to musical and other auditory stimuli in 20 autistic and typically developing children engaged in play activity at school (14). The stimuli were either short sentences, like “the birds are singing outside”, environmental noises, such as door opening and closing, or short excerpts of classical music (14). The children’s responses to the sounds were recorded using a video camera and coded for positive affect, vocalization, orientation–coordination, and anticipation–increased focus, and the results showed that the children with autism were more responsive to all stimuli than the typical children and this may reflect sensory and/or attentional difficulties (14). These results strongly suggest that music elicits special attention for children with autism and may help explain the feats of musical memory initially described by Kanner (14). Still, it is important to acknowledge that not all individuals with autism find listening to music a positive experience, which relates to misophonia, a hatred of a sound associated with an intense rage and disgust (32). In 2008, Devlin et al. observed an increase in challenging behaviour displayed by a 6-year-old when he was exposed to certain types of music (32). In their study they were able to increase the boy's tolerance for the music by using it as a differential negative reinforcement of other behaviour (32).

Approximately 10% of autistic entities have been reported to exhibit savant abilities in music, drawing, or calculation, and when it comes to music, children with ASD can easily label each pitch when several pitches are played together in a musical chord and also display enhanced recognition of alterations of single pitches in a melody, even when the altered note remains in tune with the scale of the melody such that most people would not detect this type of alteration (3,24). They can discriminate changes in less than a semitone, for instance between 1,000 Hz and 1,030 Hz. Although the ability is presented in only 20% of people with ASD, enhanced pitch perception suggests to stem from brain plasticity and reorganization triggered by genetic factors (3,24).

Furthermore, adolescents with autism show as much interest in music and spend as many hours per week listening to music as typically developing peers, as revealed by both self and parent report (24). Adults with ASD also report listening to music for similar reasons as typical listeners including to relax or to cheer up or feel better indicating that music listening is a rewarding activity for autistic people, and may thus activate the dopaminergic response system, in part due to its effect on emotions and mood regulation, as mentioned in the previous chapter (24). Although some individuals with autism may display a preference and/or aptitude for elements of music, the implications of these abilities in terms of the impact on the efficacy of interventions need more investigation (32).

Despite potential differences in perception of specific sound frequencies and in timing perception at the millisecond level, children and adolescents with ASD can accurately judge duration of musical events, perceive meter in western music, and are able to create and replicate musical melodies with coherent musical structure in a similar amount of time as typically developing peers (24). Children with ASD can accurately identify happy, sad, scary, and peaceful music, and associate images of social scenes depicting an emotion with a corresponding musical excerpt (24). Considering musical preference revealed that adults with ASD showed activation of the medial prefrontal cortex when listening to preferred happy music, the VTA for preferred sad music and the caudate nucleus for preferred and non-preferred happy music (24). Taken together, autism is associated with a unique developmental trajectory of physiological response to music evoked-emotions perhaps affecting embodied cognition, the relevance and salience of environmental stimuli, and neural and behavioural development (24).

Behavioural data collected during the study showed that autistic children identified the emotional musical excerpts as well as the neurotypical control participants (14). Consistent with results from other studies, both groups were significantly faster at identifying happy music than sad or peaceful music (14). Although these results are preliminary, they correspond well to similar studies in neurotypical individuals, which have found that affective responses to music recruit a network of paralimbic regions, like the cingulate cortex, and temporal lobe regions, such as superior temporal sulcus/superior temporal gyrus, and also the posterior inferior frontal gyrus and premotor cortices (14). These data support an affective musical experience, whereby recruitment of the MNS allows children with ASD to experience and understand emotional music (14). Furthermore, these results challenge the idea that mirror regions in the autistic brain are broken, as has previously been proposed (14).

In neuroimaging studies, children with ASD show typical recruitment of auditory areas when processing songs (24,27). However, when listening to songs compared to speech, they show greater activation in left inferior frontal gyrus and posterior brain areas and increased functional connectivity between left inferior frontal gyrus and superior temporal gyrus and between frontal and posterior areas (24,27). Similarly, in 2015, Sharda et al. found greater connectivity of the left inferior frontal gyrus with bilateral posterior temporal, right parieto-occipital, and right cerebellar regions when children with ASD listen to sung compared to spoken words (24,27). These findings suggest that although frontotemporal circuits are involved in processing both speech and song, these circuits seem more responsive to processing songs for children with ASD perhaps due to changes in pitch occurring slower in songs than in speech (24,27). Consistent with this finding, individuals with autism show enhanced processing of local auditory features, but global processing appears to be intact (27). Also, they show improved processing of simple auditory material, but findings on complex auditory processing are unclear (27). No present theory fully explains auditory processing differences in ASD, however, the results reviewed previously are most consistent with the enhanced perceptual functioning model of ASD (27).

While people with ASD have the ability to understand and appreciate music, they may have difficulties processing prosodic language cues, which can affect their ability to understand the emotional content of speech, and this is in contrast to non-autistic individuals who can understand both musical and prosodic language cues (12). Brain imaging studies suggest that the language-processing networks in the brain, such as the frontotemporal tract, the inferior frontal, and the supramarginal gyrus, may be less developed or have reduced integrity in individuals with ASD, leading to these difficulties in prosodic language processing (12). However, people with ASD can still activate their bilateral temporal brain networks when perceiving sung words, similar to neurotypical individuals (12).

4.4.3. Education vs improvisation

Three categories of therapeutic interventions for children with ASD have been distinguished: pure behavioural methods, like the Applied Behaviour Analysis (ABA); developmental methods aim to promote the development process, such as the Early Start Denver Model (ESDM); and mixed methods, such as Treatment and Education of Autistic Children (TEACCH) (22). These methods target the primary difficulties experienced by patients with ASD in social interaction and communication, using intensive interventions, at least 3–4 h per day, provided at an early age, tailored to the patient's developmental needs, promoting family inclusion and spontaneous communication with peers(22,24). These methods are more related to MT in association with education, that in the general population is associated with improvements that transfer to enhanced non-musical skills including near transfer to working memory and executive functioning (22,24).

Developing social skills is crucial for individuals with autism, but it is a difficult task and has long-term implications (24). While music therapy has been extensively studied for its benefits in relation to ASD, music education is more focused on performance skills and personal development (24). Studies investigating the effects of educational music therapy on language and communication skills in autistic children have shown significant improvements in learning target words through imitation skills and sung directives compared to spoken directives (24). The use of music videos has also been found to facilitate the learning of target words, with improvements observed in several components of oral language, such as phonology, semantics, prosody, and pragmatics (21,22). While the MT group showed a positive effect compared to the group without treatment, it did not show significant results compared to the active control group using non-musical techniques (21,22). However, some studies have shown no significant results on emotion recognition tasks using a piano melody congruent with the emotional valence of a facial expression presented with a picture or drawing (21,22).

In addition, music education of typically developing children and adolescents has been shown to result in brain plasticity, as exemplified by shorter delays in neural response to speech sounds in noise, increased neural discrimination of small pitch changes in speech and of spoken syllables enhanced neural correlates of executive functioning, and enlargement of brain areas associated with music perception including the auditory cortex and limbic areas (24). It is also worth noting that music education is related to enhanced visual perceptual skills and that joint music making promotes social skills (24).

Improvisational MT, a child-centered approach, has been found to be effective in improving joint attention, social-emotional skills, social engagement, and nonverbal social communication in individuals with ASD (9,16). The main goal of this therapy is to initiate and sustain joint attention, and improvisational music making provides an excellent way to achieve this goal, where the music therapist follows the client's musical lead, creating spontaneous music to engage musical and non-musical responses (9,16). Researchers have reported that children with ASD experience more joy and emotional synchronicity during improvisational MT than during play, and this type of therapy can be combined with other general treatment models and approaches, such as relationship-based floor time and ABA, commonly used in schools and clinics to help children improve positive behaviors. Different training and interventions may also be used alongside improvisational MT (9,12,16).

Music exploration offers a versatile approach that can incorporate different musical elements, such as tonality, harmony, melody, phrase length, and structure, to provide clients with a structured environment that caters to their social interaction needs and fosters success (9,18). Family-centered improvisational MT sessions conducted at home have demonstrated stronger outcomes in reducing clinical symptoms severity and enhancing overall functioning (9,18). This structured approach can aid in anticipating turn-taking communication, while improvisation using different melodic themes on a pitched instrument allows for creative expression (9).

Although all art forms can be considered communicative, music may be particularly well suited for supporting communication (28). Lyrics can be used to introduce a range of vocabulary concepts, provide a method for expressing emotions, and communicate larger ideas (28). Children and adults can participate lyrically by selecting, singing, or creating a line in a song (28). For individuals with complex communication needs, song lyrics can be programmed into switch-activated devices such as a portable computer or embedded into pages of a speech-generating device (28). This would allow the individual to participate in singing the song even if they are unable to use natural speech (28). Lyrics may also support targeting comprehension of intention and story line (28). For example, musical lyrics may facilitate interactions by fostering discussions such as why someone does or does not like a song or what they feel when they listen to it (28). Songs are frequently utilized in activities for individuals with ASD as they provide a means to discuss feelings and emotions that may be difficult to approach via other modalities (28).

In a study by Kim et al. in 2008, the researchers compare the effectiveness of improvisational MT and play sessions for developing positive emotional communication andjoint attention during individual sessions (32). Additionally, children engaged in longer periods of turn-taking during music situations, and showed more joy and emotional synchronicity during the music compared to play sessions (32). The results indicated that the music condition was more effective than play sessions in increasing responses to joint attention and initiating low level joint attention acts, like eye contact, while little change was observed in initiating high level joint attention behaviours such as pointing and showing (32). Although these findings suggest that music can enhance joint attention and affective behaviors, it remains unclear whether these benefits generalize to other settings (32).

Professional organizations in MT and music education can be positive and influential forces leading to increased research in vital areas related to inclusion (20). Organizations can not only help educate and motivate young researchers, but importantly, organizations can foster collaboration among knowledgeable researchers who subsequently can help develop and implement a cohesive research agenda (20).

4.4.4. Active methods vs Passive methods

Active and passive forms of MT can be distinguished as possible methodological systems, existing the possibility to combine them in the same course of treatment (31). In receptive MT, participants are guided in listening to recorded/live music, whereas active methods involve producing music, with regard to improvisation, songwriting or singing/voice work, however, this distinction has been questioned because listening may also involve an active component (22,31).

In 2006, Gold et al. conducted a report on three studies that examined the effectiveness of music compared to non-music conditions for children under 10 years old (32). While the studies reported significant improvements in gestural and verbal communication skills during music interventions, they were limited by small sample sizes and highly structured environments (32). Similarly, in 2010, Simpson and Keen used a song embedded in a PowerPoint presentation to teach three children with low verbal comprehension to label visual symbols receptively (32). The music intervention showed improvement in receptive skills for each participant and the performance was sustained three weeks after the intervention ended, however there was little generalization of these skills to other contexts (32).

Active music-making in MT sessions seemed to produce significant improvements in social skills in children with ASD (12). The value of incorporating principles and practices of music making in the treatment of language disorders is reinforced by neuroimaging research showing overlapping responses to music and language stimuli (15). In particular, MRI studies have reported activation of Broca's area during music perception tasks, active music tasks such as singing, and imagining playing an instrument. Moreover, a common network appears to support the sensorimotor components for both speaking and singing (15). Given the overlap between the language and music systems in the brain, we propose that music making, through singing or playing an instrument, may provide an alternative medium for accessing and engaging this system (15). Despite having either a reduced, or complete lack of ability to speak, many children with autism are still able to sing, and accurately reproduce complicated tunes and jingles from television commercials (15). This dissociation between singing and speaking is strikingly similar to that observed in patients with Broca's aphasia, who are often able to sing the lyrics of a song better than they can speak the same words (15).

The spontaneous music making that occurs during music therapy provides a safe structure while also allowing for creative flexibility (16). Recognizable musical frameworks such as stable pulse and meter, jazz, baroque and Spanish idioms offer security while allowing for improvisation within the structure(16). Repetition of musical ideas and phrases is an important guideline in tonal and atonal improvisation to provide direction and familiarity in the music (16). However, this type of music making should not be seen as intentionally communicative or intentional in terms of musical expression (16). If the child only engages in repetitive and rigid patterns of movement during the music making, this may indicate characteristics of ASD (16). On the other hand, there are cases where children demonstrate better interaction in a non-verbal setting, engaging in appropriate musical play without presenting with autistic-like characteristics, which may indicate a primary language delay or disorder (16).

When engaging with music, whether actively creating or passively listening, certain areas of the brain involved in cognitive, sensory, and motor processing are activated, particularly the superior temporal lobe and inferior frontal areas, and this synchronization between different areas of the brain can lead to improved sensory integration (12). Both active music-making and receptive music engagement can have cognitive benefits, such as improved attention, memory, and communication skills (12). This was demonstrated in a study where children participating in a music-based intervention showed increased connectivity between the primary auditory cortex and other regions involved in motor processing, compared to a non-music intervention (12).

Studies in biology have shown that listening to or creating music in a social setting can cause the release of neurohormones like oxytocin and neuropeptide from the posterior pituitary gland, which can increase empathy and social understanding in individuals with ASD (12). Furthermore, music has been shown to have therapeutic benefits, such as reducing pain, anxiety, agitation, and depression, and since individuals with ASD often have rigid routines, disrupting, these routines can cause significant stress and aggression (12,31).

4.4.5. Auditory integration training

There is a growing interest in utilizing alternative and non-pharmacological treatments for autism, which involve auditory and sensory integration practices. These behavioral approaches have shown promising results, with several studies providing evidence of their effectiveness (12). One such intervention is the auditory motor mapping training (AMMT) developed by Schlaug and colleagues, that aims to improve speech in minimally verbal or non-verbal children with ASD by focusing on speech prosody using slow, pitched vocalizations, engaging the auditory-motor mapping network and sensorimotor feedback regions through the use of hand tapping and intoned vocal output (3,15,23).

One successful rehabilitative technique for restoring language function in patients with aphasia is music intonation therapy (MIT), a form of AMMT (15). When employed in an intensive course of therapy with patients who have chronic non-fluent aphasia, has been shown to be successful in generating propositional speech (15). The efficacy of an adapted version of MIT in autism has also been reported in a case study of a 3-year-old nonverbal boy (15). After 35 sessions, he was able to combine words and could respond to intoned questions or statements (15). While the results of this study are very encouraging, it is possible that the therapy coincided with the boy's delayed language development (15). However, another case study of a 6-year-old girl with autism also reported the efficacy of singing in eliciting speech (15). Thus, it is possible that an adapted version could provide a useful alternative to traditional speech therapy for children with expressive language impairment linked to autism (15). Although the nature of language deficits varies greatly among individuals with autism, these two case studies indicate a particular potential of an intonation-based speech production technique in assisting children who are nonverbal (15).

In a 2009, another study utilizing music-based intervention, Schlaug et al. reported on two cases where previously nonverbal children with autism were able to speak after undergoing AMMT (1). The researchers postulated that due to its ability to strengthen the synaptic connections between various somatosensory cortical areas, music might improve deficits in the MNS found in children with autism, priming them to speak (1). In particular, the researchers pointed to previous evidence demonstrating a change in the volume and fiber density of the arcuate fasciculus in not only professional musicians but also in adult patients with Broca's aphasia who demonstrated both clinical improvement and structural changes in this front-temporal tract following an intensive course of music-based speech therapy (1). They suggested that this may also underlie the communication deficits in individuals with autism with a role for music-based therapies to supersede these deficits (1). We can conclude that these benefits are associated with the engagement of brain regions that overlap with the MNS, activated during music making activities and language, both which require imitation and synchronization (23).

Each training session involves a vocalization procedure, during which the child is encouraged to vary the intensity and length of speech sounds (15). A series of picture stimuli, combined with signs or actual objects, that represent high frequency words, actions, and social phrases are then presented using a procedure adapted from MIT (15). In addition to intonation, a key component of AMMT is the use of a set of tuned drums, or other tuned percussion instruments, to facilitate sound-motor mapping (15). The therapist introduces the target words or phrases by simultaneously intoning (singing) the words and tapping the drums on the same two pitches (15). The child progresses from passive listening, to unison singing, to partially supported singing, to immediate repetition, and finally to producing the target word or phrase on their own (15). Through intensive repetition in a comfortably structured environment that is often used in the context of therapy for autism, the previously nonverbal child learns to vocalize and possibly associate sound with meaning (15). Thus, there is positive outcomes of imitation observed in children with autism, and that indicates that AMMT could be a promising intervention technique to facilitate acquisition and/or development of social and communication skills (15).

The Tomatis method is a type of sound therapy, similar to auditory integration training, that improves listening and communication skills (19,32). A person doing the Tomatis method uses headphones to listen to electronically modified music as well as other sounds – for example, a mother's voice (32). This method is described as a sound therapy that provides auditory stimulation by attenuating low frequency and amplifying higher frequency sounds in order to focus listening on language frequencies (19,32). In 2008, Corbett et al. compared the use of the Tomatis method of music intervention with a placebo condition to determine what effect, if any the individual music intervention had on improving receptive and expressive communication in a group of eleven children, aged 3–7 years (32). In this case, there was no significant difference in language measures across the participants attributed to the treatment condition, but in general that is not the usual outcomes (32). So, it is important to understand that not all interventions can result in positive outcomes, and this is transversal to all other approaches mentioned so far (32).

In addition to activating brain regions that overlap with the putative MNS in humans, AMMT can exert its therapeutic effects in other ways (15). For example, just as MIT includes the use of hand-tapping to promote engagement of the sensorimotor network in patients with aphasia, AMMT has an important hand-motor component which incorporates the use of drums, or any of a variety of other percussion instruments, in children with autism (15).

The use of such instruments would serve the dual functions of promoting motor activity and capturing the child's interest in the therapy (15). On one hand, the simultaneous engagement of a number of sensorimotor systems during AMMT has the potential to strengthen the connections between auditory and motor regions (15). On the other hand, the act of music making itself has the potential to facilitate social communication and interaction in children with autism because it exploits their strong interest in music as well as their positive response to it (15). The value of incorporating musical instruments within the therapy context has been highlighted by a number of studies (15). For example, Kern and Aldridge incorporated singing and instrumental playing, such as drums, cabasa or sound tubes, as an intervention for increasing social interaction in children with autism (15).

4.4.6. Benefits of MT in ASD

A number of studies have reported that individuals with autism demonstrate a preference for auditory stimuli over other stimuli when the auditory stimuli is presented in the form of music, and these individuals will engage with the auditory stimuli for a longer duration than typically developing children matched on developmental age (32). One commonality between the different approaches is the use of musical stimuli and musical engagement to provide a foundation for enhanced socialization in children with ASD, leading to improved non-musical social skills (9). Researchers have also indicated that MT can increase social greeting routines, joint attention behaviours, peer interactions, communication skills, and cognitive social skills (9). Many children with ASD respond positively to music experiences, making music a safe and structured stimulus for social engagement and the practice of social skills (9). In addition to enhanced processing of music in persons with autism, the mechanisms of musical stimuli may provide a foundation for learning social skills (9).

To develop socialization skills, there were made numerous studies (32). In 2006, Kern and Aldridge embedded music into an outdoor play context and compared the baseline conditions of no directed music activities to teacher and peer mediated music intervention, and they concluded that individually composed songs, sung by teachers and peers resulted in an increase in positive peer interactions that was more apparent in the teacher-initiated sessions (32). This study provides some support for individualized interventions based on MT embedded into outdoor play routines and the involvement of peers to participate and model target behaviour (32). In 2009, Katagiri also conducted individual sessions, but to teach decoding and encoding of four emotions—happiness, sadness, anger and fear (32). It was used a counterbalance treatment-order of four different instructional conditions: no contact control; contact control where verbal instructions accompanied visuals; background music utilizing pre-recorded improvised music designed to reflect the emotion and verbal instructions; and song texts using specifically composed songs about the emotion (32). The results of the study indicate that when teaching is accompanied by background music representing the emotion, all children exhibited a greater understanding of emotions, resulting in improved empathy and social understanding (12,32). However, a common issue among most of these studies was the lack of assessment regarding the generalization of the learned skills to real-life situations and the duration of the acquired skills (12,32).

Berger's study supports the hypothesis that patterned, tempo-based rhythm interventions can bring systemic pacing under control, reduce repetitive behaviors, and alleviate anxiety in individuals with ASD (3). Children with ASD may benefit from the rhythmic and structural aspects of music, as they provide a predictable external cue to help with organizing, predicting, and responding (9). This accommodation can help with social deficits and improve planning and execution of motor patterns, which facilitates social interaction and impulse control, assisting in outlining social response times and reducing anxiety in ASD individuals (3,9). Systematic application of rhythmic stimulus has the potential to enhance neural networks associated with movement, resulting in greater impact on patients (3).

In this same scope, autistic individuals undergoing cognitive therapies may benefit from quantitative measurements of intolerance of uncertainty, perhaps targeting interventions focused on that directly, as high intolerance of uncertainty pretherapy has been found to be linked to worse post-therapy outcomes (13). Autistic cognitive differences are not necessarily negative, so harnessing neurodiversity and exploring what gives autistic people joy is vital if we are to improve well-being among the autistic population (13). Ameliorating anxiety in autistic individuals should be a primary aim for both research and clinical practices (13). Experimental studies have found in neurotypical populations that adaptive therapeutic techniques, such as cognitive reappraisal, may be optimally performed when the initial learning context and subsequent conditions for using emotional regulation are predictable (13).

Music therapy interventions have been observed to increase instances of joint attention bids, both receptive and initiated, during and after sessions, where measures of eye contact, imitation, and turn-taking have also shown improvement not only during sessions but also in interactions with others outside of the sessions (9). In 2008, Stephens conducted a study where music was used to create a social routine for engaging participants in reciprocal imitation behaviors (32). The music helped to establish a routine before participants were given the opportunity to imitate adults' modeled action and word pairs, and it was used to differentiate between the researcher's behavior (32). The study focused on the participants' willingness to engage spontaneously with the adult, and three out of four participants demonstrated spontaneous action and word imitation during social interactions, while only two maintained this behaviour during the probe situation (32).

To create effective musical experiences that promote joint attention in individuals with autism, therapists must consider various factors such as age, autism severity, presenting behaviours, and musical style and complexity (9). Personalized songs with personalized lyrics have also been used to increase independent functioning and peer-initiated interaction (32). Research has found that more complex music is effective in eliciting joint attention in children with mild to moderate ASD, while less complex music is better for children with severe impairments (9). Therefore, music therapists must carefully choose the right music and materials to promote joint attention skills, and create social experiences that provide opportunities for individuals with autism to practice their skills (9,32).

MT interventions have also been shown to improve cognitive and emotional processing skills that may directly affect social skills (9). Speech communication was shown to increase in children receiving this treatment, with the greatest benefit for children who exhibited low verbal skill, improving emotional understanding, which may affect a person's ability to relate to another person (9). In small studies, concerning the bond between ASD children and their parents or other peers, movement coordination, social communication, interaction and attention, and their overall symptoms, was the key to achieve positive outcomes (12). So when it comes to the treatment, providing psychoeducation for parents and clinicians about the potentially beneficial aspects of their child's special interests may result in identifying new methods of developing meaningful life skills including communication, vocational skills, and decreased disruptive behaviours (33).

Music therapists are not qualified to diagnose ASD, yet they can use music to gain insights into the behaviour of people with ASD during the assessment process (9). The assessment helps to determine the client's level of functioning, strengths, and weaknesses, and select appropriate treatment protocols (9,16). Music therapists track progress during music therapy sessions and use standardized clinical assessment tools, along with non-musical assessment tools, to determine if the client's functioning level is improving and if they are meeting appropriate benchmarks (9,16). Music therapists use a variety of assessment tools, such as parent-report scales, clinician-based observation scales, clinical session data documentation, and observation of the client across different settings, to determine the effectiveness of the treatment (9). These assessments are not meant to replace formal diagnostic procedures but can help identify a person's strengths and abilities in a more creative and motivating nonverbal form of interaction (9).

Music therapists use Family-centered Music Therapy (FCMT) to improve the relationship between a child with ASD and their parents, as well as to enhance their engagement in the community by promoting skill development (9). FCMT sessions involve various exercises such as a greeting song to start the session, structured improvisations, instrument games, and songs with props, all aimed at improving the child's interaction skills with their family (9,23). Outlined by Thompson et al. in 2014, this approach has been found to be particularly effective in improving the child's ability to respond to others, imitate, share, cooperate, and play, as reported by parents (9,23).

Music therapists often use parent questionnaires to evaluate the effectiveness of music therapy treatment for children with autism who may not have the communication skills to report on their own progress, and in this way they are providing a way for parents to share their perspective on the impact of the treatment on their child's behaviour and social skills (9). Although there may be some potential for bias in parent reports, they can be a useful tool for understanding the family's experience of the treatment and the impact on the parent-child relationship, along with qualitative research studies involving interviews and focus groups with parents in both individual and group settings (9,33). In addition, providing education to parents and clinicians about the potential benefits of the child's special interests can help identify new ways to develop important life skills, such as communication and vocational skills, and reduce disruptive behaviours (33).

While many studies on MT for social skills in autistic children use standardized assessments to evaluate non-musical skills, some researchers have taken a music-centred approach to outcome assessment (9). By assessing the child's musical engagement and interaction abilities, clinicians can gain insight into how the child interacts with musical stimuli and how these fit into their overall developmental framework (9). For instance, one study found that children with ASD who participated in 52 weekly MT sessions improved their ability to sing melodies, play musical scales, and reproduce simple and complex rhythmic patterns (9). These changes in music skills were accompanied by changes in standardized scores, highlighting the potential implications for inclusion in music education classrooms or overall engagement in music-making experiences (9).

Neuroanatomical evidence on how subcortical neural systems form in the human embryo brain, and the function of the same systems in directing both formation of the neocortex in the fetus and development and function of psychological functions after birth, support the view that serious difficulties with intelligent learning in early childhood are caused by gene faults or toxins that damage intrinsic motivation/emotion systems at a very early stage (26). In terms of neurophysiology, MT takes that into account, having the ability to potentially change both the structure and functional connectivity of the cortex, allowing for greater multisensory integration across cortical and subcortical domains in early developmental stages, the absence of which is widely postulated as the core underlying neurophysiologic aberration in ASD (1,26). Early evidence suggests a strong improvement across clinical domains and a large body of evidence demonstrates structure and functional changes in the brain following a period of active musicality in key areas, including the MNS, that may serve as the mechanism through which clinical improvements for patients engaged in musical training occur (1,26).

Further, in 2008, Chen et al. have suggested an integral association between auditory and motor systems in the milieu of rhythm (3). Interestingly, two years later, Kornysheva et al. have compared the effect of desired to not desired musical rhythms on the premotor and cerebellar areas using functional magnetic resonance imaging and indicated that the desired tempo improved the activity in the ventral premotor cortex (3). It has also been found that those structural and functional variances in the sensorimotor regions of the cerebellum and sensorimotor cerebral-cerebellar circuits can cause motor control disability and repetitive and stereotyped behaviours in autism (3).

Individuals with ASD have been found to have a preference for music over verbal material, possess superior pitch memory and recognition, and enjoy dissonant music more than those with typical development (12). They use music for a variety of purposes, including addressing cognitive, emotional, and social needs such as mood management, personal growth, and social inclusion . The notion of neurodiversity recognizes and respects differences associated with autism as a natural human variation to be valued and celebrated as part of one's identity rather than being cured or treated, and with this concept MT aims to be effective by using a range of approaches, including behavioural, biomedical, developmental, educational, humanistic, adaptive music instruction, and other models (4,17).

5. Review's limitations

The limitations of this review lie on common problems from the various studies that were selected, including the size of the samples, the qualification of the professionals involved, the duration of the study or the intervention, the age ranges, the heterogenicity, the generalization, the type of research and therapy, and the obtained outcomes.

The majority has small samples, which compromises the strengthen of the clinical applicability of the results and how enduring the effects of MT are. In the context of wider literature, further investigation should be conducted in larger and more diverse samples, including adults with ASD and elderly individuals with ASD, utilizing larger sample sizes. Another related issue is the wide age range or the lack of focus when it comes to select a specific generation. There is more work done on children and adolescents than adults and elderly people, and it is understandable because autism is a disorder that begins early in life. However, there is still some questions on how it all evolves trough life and how music as therapy can act in latter life periods.

Most studies had a non-controlled design, and when a control group existed the allocation of the treatment was not necessarily randomized questioning the impact of possible confounding biases. Also, standardized and published tools were not always used to evaluate the outcome of MT and a lot of studies included little generalization of skills to other contexts, raising questions about the social validity of these interventions in the lives of children with autism. As individuals with autism experience particular difficulty in generalizing skills to contexts other than the training context and comprehension is often only in highly familiar contexts, this creates questions as to the individual's level of comprehension during intervention or whether they are responding to the contexts and cues provided during the intervention. Consequently, this raises questions on how enduring the effects of MT are out of the intervention in terms of verbal and non-verbal communicative skills, because there is a lacking of longitudinal and long-term studies and outcomes.

Another issue with MT interventions is their heterogeneity, especially in educational MT, which makes it challenging to compare studies and render meta-analysis calculations invalid. It may be beneficial to examine ASD symptoms comprehensively to observe the effects of music or MT on specific symptoms of ASD. Moreover, it is vital to note that MT requires professionals to have specialized academic and clinical training. Training programs in MT should prioritize clinical MT techniques, as well as developing the therapist's personality and clinical sensitivity. Many music researchers lack the background and interest to conduct research on this topic, and music therapists may have expertise in other areas. Consultation and collaboration with knowledgeable individuals, parents, and service providers are recommended, preferably in inclusive environments like classrooms, college or university courses.

Both music therapists and non-music therapists have noted the lack of evidence supporting the efficacy of MT, with most studies being inconclusive or only suggestive. This uncertainty surrounding non-pharmacological interventions commonly used in clinical practice for patients with ASD highlights the need for further research. Future studies should mimic clinical practice settings in terms of frequency, duration, and therapy techniques to obtain more precise results. Given the broad spectrum of clinical conditions in ASD, it is crucial to understand the individuality of each person with ASD to achieve more effective and personalized interventions.

6. Conclusions and final considerations

The social models of disability emphasize that societal attitudes and barriers play a significant role in disabling individuals with special needs. This perspective focuses on the interplay between the individual, society and intervention efforts on societal accommodation, rather than modifying the behaviour of the individual. In the case of individuals with autism, this means considering their unique needs, goals, and contributions to society, and promoting interventions that prioritize their preferences, motivations, and choices. It is essential to recognize that environmental and systemic factors beyond the control of the individual may also contribute heavily to autistic distress. Physical, sensory, and social environments are often not adequately adapted for autistic individuals, and they may experience high rates of trauma, stigma, and victimization.

Thus, any effort to change an individual's cognitions or behaviour must always be situated within an understanding of such societal factors. The appreciation of diversity, self-determination, and acknowledgment of unique societal contributions that individuals with autism can offer are increasingly influential in the conceptualization of autism. This notion extends beyond academic scholarship and has resulted in more employment opportunities for those on the autism spectrum. Research efforts need to examine the explicit and implicit theories that guide individuals, systems, and institutions interfacing with autism to create a more autism-friendly society.

The lack of social, interpersonal, and motor skills in ASD individuals can negatively impact their everyday life, so treatment for ASD should focus on improving functional motor, social and communication skills. Several studies have reported that individuals with autism have a preference for auditory stimuli, particularly music, and engage with it for longer durations than typically developing children matched on developmental age. MT has been shown to increase social skills, such as social greeting routines, joint attention behaviours, peer interactions, communication skills, and cognitive social skills, along with improvement eye contact, imitation, and turn-taking.

Additionally, music stimuli provides a unique accommodation for social deficits in ASD as rhythm and music can help with planning and execution of motor patterns, facilitating social interaction and assisting with impulse control. Rhythmic interventions can ease repetitive behaviours and, consequently, reduce anxiety, so quantitative measurements of intolerance of uncertainty may benefit autistic individuals undergoing cognitive therapies. Moreover, clinicians must consider several factors of the musical experience, such as age, level of ASD, presenting behaviours, and the type of music, to develop effective musical experiences for joint attention. Effective treatments require adaptive behaviours from caregivers and teachers, providing stable, structured, and protective environments, as well as instructive training. So it is necessary direct support for the child's motives and compensation for difficulties with physiological self-regulation. Using active approaches, music becomes a tool for self-expression, allowing individuals with autism to express themselves in ways that they may not be able to do verbally, along with improvements in creativity and self-conscience. In contrast, MT can be incorporated into the lives of individuals with autism as a teaching tool to help them learn new concepts in a passive way, also making them more self-aware. This duality of interventions provides a more directed and individualized treatment, which promotes better outcomes.

Neuroplasticity refers to the brain's ability to change and adapt in response to various experiences and stimuli. In the context of autism, research has shown that individuals with autism have differences in neural connectivity and plasticity compared to neurotypical individuals. Music can be used to enhance neuroplasticity, predominantly in the development of cortical plasticity, and to rewire sensorimotor cerebral-cerebellar circuits to improve motor control and repetitive behaviours. It can strengthen the synaptic connections between various somatosensory cortical areas, such as frontotemporal and frontoparietal regions, the amygdala-hippocampal complex, cerebellum, basal ganglia, and anterior and posterior cingulate regions.

MT and other forms of non-verbal communication can be effective in modifying autonomic state, engaging attention, and improving skill development by meeting the child where they are and picking up on their interests, purposes, and sensitivities. Although there is still some work to do, the growing field of music and ASD research holds promise for understanding the social and emotional profiles of individuals with ASD and providing strength-based interventions.

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