Neurologic Music Therapy

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Introduction

Music has played a prominent role in the clinical and research literature on autism spectrum disorder[1] (ASD). Kanner's (1943) first descriptions of cardinal features of autism included several references to intriguing music-related behaviors displayed by 6 of the 11 cases he described. For instance, Kanner reported that cases 1, 2, 3, 6, and 9 had an atypical interest for music and were able to discriminate and name a large number of musical compositions—an intriguing observation when considering these children's developmental stages. This first account of early musical preoccupations, extraordinary musical memory, and unusually early enjoyment and appreciation of music in children with autism instigated important research questions about the clinical and functional implications of music in autism.

The clinical application of music to mediate the developmental and therapeutic processes in autism has a long history (for review, see Reschke-Hernandez, 2011) and is one of the most frequently used treatment strategies for autism within clinical and educational settings (Goin-Kochel, Mackintosh, & Myers, 2009; Goin-Kochel et al., 2007; Green et al., 2006; Hess et al., 2007). In this chapter, we discuss the current state of clinical research in the area. We start by outlining recent neuroimaging and behavioral research investigating the unique relation between music and preserved cognitive skills in autism. The next sections discuss key concepts underlying Neurologic Music Therapy and the impact of the neuroscience model for clinical and research practices. The discussion of the current state of clinical research is centered on results from controlled clinical studies investigating the effects of music-based interventions to address core features of autism, such as communication, social, and emotional skills. To conclude, we discuss new directions for expanding the clinical scope of music-based intervention, including under-researched functions, such as motor and attention control.

Music-Related Skills in Autism

There is robust research evidence that music is a domain of preserved skills and interest in individuals with ASD. Empirical behavioral research has demonstrated that individuals with autism often have intact or superior pitch and timbre processing abilities (Bonnel et al., 2003; Heaton, 2005, 2009; Heaton, Hermelin, & Pring, 1998; Heaton et al., 2007; Mottron et al., 2000), enhanced melodic memory (Heaton, 2003), preserved abilities to

[1] Henceforth also referred to as "autism".

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understand the rules of Western musical harmony (Heaton et al., 2007) and process melodic complexity (Thaut, 1988), and intact rhythm synchronization capacity (Tryfon et al., 2017). One particularly intriguing research finding in the ASD auditory research literature is that exceptionally good pitch information processing appears to be a common characteristic in autism (for review, see Heaton, 2009). It has been shown, for instance, that autistic children without musical training are often able to accurately associate musical tones to their corresponding note labels—a skill known as absolute pitch, a rare ability to identify or produce the pitch of a tone without reference to an external standard (Heaton, 2003; Heaton, Pring, & Hermelin, 2001; Heaton et al., 2008). This enhanced ability to process simple auditory stimuli such as musical tones contrasts with a generally diminished ability to process social and more complex sounds such as speech, a paradox that has served as a model to study atypical sensory processing in ASD (Just et al., 2007; Mottron et al., 2000, 2006; Ouimet et al., 2012).

Emerging evidence also emphasizes the role of music stimuli in studying emotion processing in ASD. Several studies have shown, for instance, that individuals with autism are able to properly identify the positive and negative emotional valence of emotional musical stimuli (Brown, 2017; Gebauer et al., 2014; Heaton, Hermelin, & Pring, 1999; Quintin et al., 2011). Moreover, recent neuroimaging evidence suggests that cortical and subcortical circuits underlying affect and reward are preserved in individuals with ASD (Caria, Venuti, & De Falco, 2011). Collectively, these studies indicate that although ASD individuals have significant deficits in processing complex emotional cues within the social context, their ability to identify the emotional content of complex nonsocial affective stimulus such as music is generally preserved.

Despite speech disabilities in autism, recent neuroimaging research has demonstrated that speech-analog music abilities are frequently preserved (Lai et al., 2012; Sharda et al., 2015). A recent neuroimaging study investigating speech and song processing in low-functioning children with ASD found that Broca's area (left inferior frontal gyrus)—which is typically underactivated during speech processing in children with autism relative to controls—was significantly activated during song processing, indicating that children with ASD may be more effectively engaged in musical stimuli (Lai et al., 2012). Another imaging study expanded this finding by showing that, while frontotemporal connectivity is significantly disrupted during spoken-word perception, this network is preserved during sung-word processing, suggesting alternate mechanisms of speech and music processing in ASD (Sharda et al., 2015).

Collectively, this growing body of research evidence corroborates anecdotal reports that music has a profound impact on children with autism and demonstrates that music-related skills in domains such as memory, auditory perception, emotion, and language are significantly preserved in ASD. By focusing on the individual's strengths, interests, and potential, music may be a particularly resourceful therapeutic approach for autism with strong potential to promote and facilitate functional changes in non-musical brain and behavior functions.

What Is Neurologic Music Therapy?

Neurologic Music Therapy (NMT) is the clinical application of music and its elements as a therapeutic medium to address cognitive, developmental, adaptive, and rehabilitative goals in the areas of cognitive, psychosocial, language, sensory, and motor functions of individuals with disabilities. NMT consists of 20 standardized evidence-based music therapy techniques directed toward non-musical therapeutic goals and its scientific theories are based on the clinical neuroscience of music perception, cognition, and production.

Three critical components need to be considered when using music in a therapeutic context. First, the music exercises used in therapy need to be provided by a qualified and accredited professional who is trained to understand the music theory, history, and performance, as well as the sciences underlying the therapeutic and rehabilitative aspects of music-based intervention.

Second, music-based interventions must be determined based on a diagnostic therapeutic goal. Third, in order to use music as a therapeutic tool, a therapist must understand the scientific foundations of the influence of music on functional changes in non-musical brain and behavior functions (Thaut & Hoemberg, 2014).

NMT interventions and therapeutic protocols follow the Transformation Design Model (TDM), which provides a systematic step-by-step approach to designing, implementing, and evaluating the treatment process (Thaut & Hoemberg, 2014). There are six steps:

1. Diagnostic and functional/clinical assessment of the patient.
2. Development of therapeutic goals and objectives.
3. Design of functional, non-musical therapeutic exercises.
4. Translation of non-musical exercises (step 3) into functional therapeutic music exercises.
5. Outcome reassessment.
6. Transfer of therapeutic learning to functional, non-musical, "daily life" activities.

Clinical/functional assessment is typically non-musical in nature and is completed in order to determine the client's current level of functioning, including information about the person's medical history, cognition, social and physical abilities, vocational or educational background, emotional status, communication skills, family, and leisure skills. The assessment is also designed to identify the appropriateness of music therapy as a treatment and assist the therapist in selecting the optimal treatment based on target areas of need. The use of validated and reliable non-musical assessment tools is critical to determine the client's progress throughout the treatment process and to enable communication with other members of the interdisciplinary treatment team. Musical materials and music-based assessments may also be used to assess non-musical functioning.

Treatment selection is based on the treatment target area(s) and goals. A treatment plan identifies the goals and objectives that will be addressed during treatment specifying the target area, the parameters of the behavior that the client needs to accomplish, the criterion and qualifiers for that behavior, and the target date of achievement. Importantly, the design of therapeutic music exercises and activities is based on functional, non-musical therapeutic exercises and stimuli that are translated into functional therapeutic music experiences. There are defined NMT protocols that can be implemented according to the treatment target. Musical Speech Stimulation (MUSTIM), Rhythmic Speech Cueing (RSC), and Symbolic Communication Training Through Music (SYMCOM) are examples of NMT techniques designed to address speech and language functions, whereas Rhythmic Auditory Stimulation (RAS) and Patterned Sensory Enhancement (PSE) are focused on different aspects of motor rehabilitation (Thaut & Hoemberg, 2014). Neurologic Music Therapy treatment techniques are standardized in terminology and application but are adaptable to meet each patient's unique needs.

Effective assessment of the patient's status and progress throughout the treatment are also vital aspects of the treatment process. The reassessment may occur after each session, intermittently during the treatment process, or at the end of the treatment protocol. Therefore, the use of validated, standardized, non-musical assessment tools that are sensitive to capturing changes over the determined assessment period must be administered.

Assessments and treatment plan must be substantiated by a scientific understanding of the influence of the music or neural mechanisms underlying the musical responses on functional changes in non-musical brain and behavior functions. This cardinal principle in NMT is based on the focus on music as a biological language whose structural elements, sensory attributes, and expressive qualities engage the human brain comprehensively and in a complex manner. In NMT, music as a therapeutic agent does not operate as a cultural artifact or carrier of sociocultural values, but rather it operates as a core language of the human brain and can be applied effectively to train and retrain the injured brain. In this way, research transforms the clinical practice and is crucial to guide treatment protocol choices and dispel the use of activity-based or non-goal-driven treatments and to establish treatment goals that can be generalized to improved behavior beyond the therapy session.

From a Social Science to a Neuroscience Model

There is a long history of the use of music and musical elements in the treatment of ASD. The first accounts of early musical preoccupations, extraordinary musical memory, and unusually early enjoyment and appreciation of music co-occurring alongside social and communicative disabilities in children with autism motivated the first investigations and application of music as therapy for ASD. Expectedly, the emphasis of music therapy practices during the first decades was primarily on the autistic children's usual musical abilities and attraction to music and the use of music for self-expression, socialization, psychological enrichment, and recreation (for review, see Reschke-Hernandez, 2011).

Music therapy evolved as a therapeutic discipline and health profession in parallel with the advances in ASD research. With a better understanding of the clinical characterization and diagnostic criteria and the inclusion of autism as a distinct disorder to the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 1980), music therapists started to develop therapeutic techniques to address specific areas, such as communication and social skills. Modifications of techniques from fields such as psychology, speech-language pathology, and special education were incorporated into music therapy practices resulting in the formulation of music therapy theories. For instance, Behavioral Music Therapy uses music to facilitate a change in unhealthy patterns of behavior utilizing principles such as operant conditioning, classical conditioning, and contingent reinforcement (reviewed in Davis, Gfeller, & Thaut, 2008; De l'Etoile, 2008). Creative Music Therapy (Nordoff & Robbins, 1977) provided a theoretical foundation for the use of improvisational music therapy with children with autism and other disabilities. In Creative Music Therapy, free instrumental and/or vocal improvisation is used to encourage inner creativity, emotional awareness, self-expression, self-confidence, and self-actualization. Therefore, during the period between 1940 and 1990, innovative music therapeutic techniques and methods were developed for a broad range of functional domains and the clinical practice of music therapy gained significant momentum. However, there was a disconnect between music therapy clinical practice and clinical research. As Reschke-Hernandez (2011) pointed, the first decades of music therapy clinical practice for autism were characterized by 'trial and error' and the research conducted during this time consisted primarily of case studies without quantitative data analysis, with the majority of publications not including rigorous and systematic descriptions of the techniques.

Since the early 1990s, the advent of modern research techniques in cognitive neuroscience, such as brain imaging, brain-wave recordings, and kinematic motion analysis, has provided a foundation for a new research agenda that is scientifically based called Neurologic Music Therapy. The shift from a social science model to a neuroscience model of clinical and research practice emphasized the need to improve the level of research evidence through rigorous clinical trials. The Rational-Scientific Mediating Model (RSMM) (Thaut, 2000) was developed to provide a systematic method of conducting high-quality research in music for rehabilitation and therapy in order to establish evidence-based interventions and theoretical foundations. The RSMM establishes four steps for clinical and research practice:

1. *Musical response models*: Investigating the neurological, physiological, and psychological processes underlying the musical behavior response. Understanding the brain processes (e.g., perception, cognition, motor control) involved in the creation and perception of music is the first step in the research process.

2. *Parallel non-musical response models*: Investigating overlaps and shared processes between musical and non-musical brain/behavior function in similar areas of cognition, speech/language, and motor control. Research at this level aims to establish a meaningful link between musical behavior and non-musical behavior.
3. *Mediating models:* Investigating whether music can influence non-musical brain and behavior functions. If a parallel process has been identified at step 2, the researcher then formulates hypotheses to study the mechanisms underlying the effect of music on non-musical function, that is, the mediating response.
4. *Clinical research models*: Investigating whether music can influence (re)learning and (re)training in therapy and rehabilitation. When positive mediating effects have been established at step 3, the findings are then investigated in a clinical, translational context. Interventions and treatment protocols are tested with patient populations to examine the long-term, therapeutic effects of music in (re) training brain and behavior function.

The shift from social science to a neuroscience model of clinical and research practice, and the development of epistemological models such as the RSMM, provided a scientific framework to guide the generation of knowledge concerning the linkage between music, therapy, and rehabilitation. This framework has helped to bridge the gap between clinical practice and clinical research leading to the establishment of Neurologic Music Therapy as an evidence-based model of music-based interventions based on translations of brain processes in music perception, cognition, and production to non-musical brain and behavior functions in neurorehabilitation and neurodevelopment.

Current State of Clinical Research

Traditionally, clinical and research practices in music therapy have focused predominantly on outcomes related to the cardinal diagnostic features of autism: communication, social, and emotional skills (Table 1). The following overview and critical appraisal of the current research literature follows the steps established in the RSMM; that is, we will first assess the scientific evidence regarding the effect of the musical behavior (i.e., singing, playing an instrument) on the non-musical behavior (i.e., verbal production, social responsiveness), and then overview the clinical research models and interventions developed to address the non-musical brain and/or behavior function. This discussion will be based on findings from randomized controlled trials and controlled clinical trials published in peer-reviewed journals from 2000 to 2016. For systematic and narrative reviews of recent clinical studies in music therapy for autism, including case studies and single-group studies, see Accordino, Comer, and Heller (2007), Geretsegger et al. (2014), James et al. (2015), LaGasse (2017), and Simpson and Keen (2011). It is important to clarify that music therapy interventions exclude sound therapies (Corbett, Shickman, & Ferrer, 2008; Lundqvist, Andersson, & Viding, 2009; Sinha et al., 2006), background music (Carnahan, Basham, & Musti-Rao, 2009), robotic interventions (Srinivasan et al., 2016), or Melodic Based Communication Therapy (MBCT) (Sandiford, Mainess, & Daher, 2013).

Communication Outcomes

Social communication, language and speech deficits in autism are traditionally the primary target areas in music therapy (Geretsegger et al., 2014; James et al., 2015).

Mediating Models: Parallel Processes Between Music and Language/Communication

Music and speech, especially in singing, share multiple control processes with regard to auditory, acoustical, temporal, neuromuscular, neural, communicative, and expressive parameters (Wan et al., 2010). In addition to the behavioral similarities, research has demonstrated that music and language have reciprocal cerebral neuroanatomical structures and similar patterns of

Table 1 Music therapy interventions in ASD treatment: summary of the current clinical literature

Study	Sample size	Age (years)	Treatment target	Music therapy intervention	Design	Results
Communication outcomes						
Lim (2010)	50	3–5	Verbal production	Developmental speech and language training through music (DSLM)	Randomized controlled trial	Inconclusive
Lim and Draper (2011)	22	3–5	Verbal production	Music training (music incorporated applied behavior analysis verbal behavior)	Crossover design	Inconclusive
Gattino, Riesgo, and Longo (2011)	24	7–12	Verbal and nonverbal social communication	Relational music therapy (unstructured improvisation)	Randomized controlled trial	Inconclusive
Social outcomes						
Kim, Wigram, and Gold (2008)	15	3–5	Nonverbal social communication skills and joint attention	Improvisational music therapy	Randomized controlled trial	Positive
Kim, Wigram, and Gold, (2009)	15	3–5	Interpersonal responsiveness and joint attention	Improvisational music therapy	Randomized control trial	Positive
Thompson, Mcferran, and Gold, (2014)	23	3–5	Social engagement	Family-centered music therapy	Randomized control trial	Positive
LaGasse (2014)	17	6–9	Social responsiveness	Structured music therapy	Randomized control trial	Positive
Emotional outcomes						
Katagiri (2009)	12	9–15	Emotional expression and understanding	Improvisational music therapy	Randomized control trial	Inconclusive

cortical activation of Broca's area (left inferior frontal gyrus), the primary and secondary auditory cortices (i.e., bilateral temporal and right inferior frontal lobe), and the primary motor cortex that are involved in both music and speech processing (Brown, Martinez, & Parsons, 2006; Koelsch et al., 2004; Patel, 2003). Recent neuroimaging studies have also demonstrated that, while frontotemporal connectivity is significantly disrupted during spoken-word perception, this network is preserved during sung-word processing (Lai et al., 2012; Sharda et al., 2015). Additionally, correlational studies show that typically developed children who undertake instrumental music training outperformed musically naïve children on tasks of verbal memory, verbal fluency, and nonverbal reasoning (Forgeard et al., 2008; Ho, Cheung, & Chan, 2003).

Clinical Research Evidence

Speech production was the primary treatment target goal of recent randomized clinical studies. Lim (2010) addressed acquisition of target words using a Neurologic Music Therapy technique called "developmental speech and language training through music (DSLM)" (Thaut & Hoemberg, 2014). DSLM is designed to use developmentally appropriate musical materials and experiences to enhance speech and language development through singing, chanting, playing musical instrument, and combining music, speech, and movement. In this study, prerecorded videos of songs composed by the music therapist to include the target words were presented to children with ASD with various levels of impairment. The control conditions were prerecorded videos of the speech stimuli using only the text of the songs or no treatment. The intervention was administered twice a day for 3 days, and posttests were completed after six training sessions. Results indicated that high- and low-functioning participants in both music training and speech training increased verbal production in the post-intervention assessment. However, low-functioning children demonstrated greater gains in the music condition. On a subsequent study, Lim and Draper (2011) added music to an applied behavioral analysis verbal behavioral approach. The music intervention consisted of singing the verbal instructions and songs composed by the music therapist to include the target words and phrases to be learned, whereas in the speech control condition, the therapists spoke the same texts for the sentences and directions. Children with ASD (verbal or preverbal) received both music and speech training for 3 days a week for 2 weeks (the order of intervention was counterbalanced). The results indicated that both music and speech training had a significant effect on the verbal operant production compared to the no-training condition, however, there were no differences between the treatment groups. The measure in favor of the music training condition was echoic production of speech. Although these studies suggest that music interventions are as effective as standard speech training techniques, and that low-functioning children may benefit more from music-based intervention (DSLM), these results are based on very short intervention periods requiring further investigation.

The main intervention approach in traditional music therapy[2] to address socio-communication skills in autism is musical improvisation (Geretsegger et al., 2015; Wigram & Gold, 2006). Within this therapeutic approach, music is utilized as a medium for self-expression, communication, and interaction and toward the development or rehabilitation of appropriate socio-emotional functioning. In some music therapy methods, such as the Creative Music Therapy (Nordoff & Robbins, 1977) and relational music therapy (Cabrera & Caniglia, 2007 as cited in Gattino et al., 2011), music improvisation is based on an intuitive and moment-by-moment process where the music therapist identifies musical elements (tempo, rhythmic patterns, dynamics of expression, pitch range, and melodic contour) in the child's musical and non-musical behavior and musically matches the child's emotions, facial expressions, or physical bearing, to attract and engage the child. The interaction between the therapist and the child happens predominantly through nonverbal and multimodal cues (i.e., eye contact, facial expressions, vocal or instrumental exchanges), and there are no structured protocols for intervention.

Gattino et al. (2011) investigated the effect of improvisational music therapy on verbal, nonverbal, and social communication skills. Unstructured music improvisation intervention was administered weekly for 16 weeks to a group of children diagnosed with autistic disorder, pervasive developmental disorder not otherwise specified (PDD-NOS), and Asperger's syndrome, while the control group did not receive music therapy treatment in addition to standard care. Results revealed no statistically significant differences between treatment and control groups in all outcomes assessed. Interestingly, a subgroup analysis indicated that nonverbal communication significantly increased after music intervention only for children with autism (but not PDD-NOS and Asperger's). However, Given the small sample of children with autism in the experimental group, limited conclusions can be made.

In summary, there is research evidence from neuroimaging and correlational studies to support the therapeutic use of music in the development of verbal and nonverbal communication skills in children with autism, however, there is limited high-quality intervention research in this area. Studies investigating music therapy interventions for speech production indicated that music therapy is as effective as standard speech interventions; however, further investigation is warranted given that these studies assessed very short-term interventions (Lim, 2010; Lim & Draper, 2011). Similarly, limited conclusions can be made in relation to the effectiveness of improvisational music therapy for verbal and nonverbal communication skills for ASD due to small sample in Gattino et al. (2011).

[2]Traditional music therapy here refers to techniques based on the social science model, not Neurologic Music Therapy.

Social Outcomes

There is a long history of the use of music therapy interventions to target social skills. One commonality between the different music therapy approaches is the use of musical stimuli and musical engagement to provide a foundation to improve non-musical social skills in children with ASD (LaGasse, 2017).

Mediating Models: Parallel Processes Between Music and Social Behavior

Music is an engaging, multisensory, and social activity. There is robust research evidence that the rhythmic and structural components of musical stimuli provide highly predictable external cues that facilitate anticipation, planning, and entrainment of motor sequences (Thaut, McIntosh, & Hoemberg, 2015). The ability to predict and anticipate other people's actions and intentions, and build shared representations is essential in social behavior (Brown & Brüne, 2012; Haswell et al., 2009). Overy and Molnar-Szakacs (2009) have proposed that music is perceived not only as an auditory signal but also as an intentional, hierarchically organized sequences of expressive motor acts, and that the human mirror neuron system allows for co-representation and sharing of a musical experience between agent and listener. Studies have found that synchronous movements during rhythmic actions or music-making encourages high levels of social cooperation and prosocial behavior (Cirelli, Einarson, & Trainor, 2014; Kirschner & Tomasello, 2010; Valdesolo, Ouyang, & DeSteno, 2010). For example, typically developing children who participated in joint music-making with adult partners showed more spontaneous prosocial behaviors of helping and cooperating than those who engaged in a dyadic non-musical storytelling activity (Kirschner & Tomasello, 2010).

Clinical Research Evidence

Kim et al. (2008) investigated the effects of improvisational music therapy on joint attention behaviors. Pre-school children with autism undertook 12 weekly improvisational music therapy sessions and 12 weekly play sessions with toys as control condition (the order of interventions was counterbalanced with 1-week washout period). In both conditions, the first part of the session consisted of child-led activities, where the therapist only supported and elaborated the child's play, and in the second part of the session the therapist introduced modeling and turn-taking activities to engage the child's focus of attention and interest. Joint attention and prosocial behavior were assessed with standardized tools and microanalyses of the target behaviors through analysis of video recordings of the sessions. Improvement in initiating joint attention bid, joint visual attention, eye contact duration, and alternating eye contact were observed during and after music therapy session but not in the control condition. In a subsequent analysis of this data, Kim et al. (2009) focused on the social-motivational aspects of the interaction between the child and the therapist during improvisational music therapy. Behavioral microanalysis of the video recordings of the therapy sessions assessed frequency and duration of the participant's emotional and motivational responsiveness (joy, emotional synchronicity, initiation of engagement). Results indicated that emotional and responsiveness behaviors were significantly more frequent and longer in duration in the music therapy intervention than in the toy play condition. These results are, therefore, in favor of the use of improvisational music therapy to address joint attention behaviors and prosocial behaviors.

In LaGasse (2014), children with autism received either music therapy or non-musical social skills intervention for 5 weeks. The music therapy intervention consisted of structured group musical experiences to promote cooperative play and communication, whereas the control group participated in similar group experiences with games and non-musical activities. Social outcome measures focused on eye gaze, joint attention, and communication. Results indicated that children in the music therapy group improved significantly in measures of joint attention with peers and eye gaze toward other persons in relation to the control group. Another positive result in favor of the music therapy intervention was parental perception of social skills, with greater improvements observed in the music therapy group. The study did not find, however, significant differences between groups in measures of communication, such as initiation of communication with another person or response to communication. These results corroborate the findings of Kim et al. (2008), suggesting that music therapy may be effective for increasing joint attention behaviors.

Family-centered music therapy was also used to assess social engagement in children with severe ASD (Thompson et al., 2014). In this study, parents were encouraged to actively participate in home-based music therapy sessions and collaborate with the therapist in the musical activities. The intervention consisted of structured activities designed to address shared attention, turn-taking, response, and initiation of joint attention, whereas the control group did not receive music therapy in addition to standard care. Primary outcome measures were based primarily on parent-report assessment. Results indicated that parents perceived significant improvement in the quality of their child's social skills after music therapy intervention in relation to the control condition. Assessment of video recordings also suggested improvement in the level of interpersonal engagement within music therapy sessions. Although encouraging, these findings must be interpreted with caution given that the results were predominantly based on parental assessment, which are prone to bias.

In conclusion, there is support from basic neuroscientific research for the investigation of music-based interventions to address social skills (Cirelli et al., 2014; Kirschner & Tomasello, 2010; Valdesolo et al., 2010). Overall, there are promising indicators for the potential use of music-based intervention to address social communication skills, more specifically, joint attention behaviors (Kim et al., 2008, 2009; LaGasse, 2014). Increase in interpersonal engagement was also reported (Thompson et al., 2014); however, given the self-report nature of the assessment, further investigations are necessary to confirm this finding. Similar to the research in communication, intervention protocols differ widely between studies and are often a collection of different activities which make it difficult to replicate and to pinpoint sources of therapeutic effects. Furthermore, the frequent use of observational video analysis for behavioral data analysis raises questions regarding standardization and objectivity of the measurements. Replication and objective assessment of behavior via video recordings are usually a problematic matter in improvisational music therapy given the subjectivity and lack of protocol structure which are characteristic of several improvisational music therapy methods (but see Thaut & Hoemberg, 2014). Documentation and assessment tools, both quantitative and qualitative, have been developed for the analysis and interpretation of musical material in creative improvisation (for review, see Wigram & Gold, 2006). However, to address the replication issue, future clinical research studies need to include thorough descriptions of the musical exercises and the explanation of how the various musical features are being used to promote the desired nonmusical behavior and/or experience.

Emotional Outcomes

Although communication and social skills have historically been the primary focus of music therapy intervention for ASD, self-awareness, emotional expression, and understanding have also been treatment targets in traditional music therapy (Geretsegger et al., 2014; James et al., 2015).

Mediating Models: Parallel Processes Between Music and Emotion

There is extensive basic neuroscience and music perception research investigating the link between music and emotion (for review, see Gabrielsson & Lindström, 2001; Koelsch, 2015; Zatorre & Salimpoor, 2013). Numerous studies have investigated the influence of musical structures (e.g. tempo, loudness, intonation, deviations in note timing) on perceived emotion (reviewed in Gabrielsson & Lindström, 2001;

Juslin & Sloboda, 2001). Neuroimaging research has also provided evidence of the neural correlates of music-evoked emotions (for review, see Blood, Zatorre, & Bermudez, 1999; Koelsch, 2014; Zatorre & Salimpoor, 2013). It is well-established, for instance, that music modulates the activity of the brain networks involved in reward and emotion regulation (Koelsch, 2014). Moreover, recent behavioral and neuroimaging studies have suggested that, although ASD individuals have significant deficits in processing complex emotional cues within the social context, their ability to identify the emotional content conveyed in music is preserved (Brown, 2017; Caria et al., 2011; Gebauer et al., 2014; Heaton et al., 1999; Quintin et al., 2011).

Clinical Research Evidence

There is a paucity of systematic clinical research investigating the potential use of music therapy to facilitate emotional understanding in children with ASD. Katagiri (2009) studied the effectiveness of music-based intervention to facilitate understanding of four different emotions: happiness, sadness, anger, and fear. In the improvisational music therapy condition, structured improvisations referencing the targeted emotions were prerecorded and presented to the participant while the therapist gave verbal instructions about each of the emotions. In a second experimental condition, the emotions were taught by singing a song composed by the therapist which included lyrics referencing the targeted emotions. The control conditions included verbal instructions only or no purposeful teaching of the targeted emotion. Results suggested that children learned more effectively in the improvisational music therapy condition than the other tested conditions. However, this finding should be interpreted with caution since the study did not include validated and standardized assessment measures. Moreover, verbal content and/or instructions were incorporated in all conditions, which could be a potential confound given that the therapist was not blinded to the experimental conditions.

Therefore, although basic research has provided extensive evidence to support the use of music-based therapy to facilitate emotional expression and understanding, the lack of well-designed and systematic clinical research instigates further investigations.

Expanding the Clinical Scope: New Directions

From this brief overview of the current clinical research, it is possible to note that Music therapy interventions have focused predominantly on the cardinal clinical features of autism. However, individuals with ASD often display several other debilitating impairments, such as motor control and attention deficits. There are compelling research evidence suggesting that motor and attention deficits are not only secondary impairments or comorbidities but have direct impact on social and communication skills. Importantly, motor control and attention function have been successfully addressed by interventions in Neurologic Music Therapy with other clinical populations.

Motor Control Deficits in ASD

Parents and clinicians often report that children with autism display significant and pervasive motor impairments that are not associated to motor stereotypies. Motor deficits in autism include impairment in basic motor control such as clumsy gait (Fournier et al., 2010), poor balance and postural control (Bhat, Landa, & Galloway, 2011), delayed motor development (Fatemi et al., 2012; Wang, Kloth, & Badura, 2014), impairments to reaching and grasping (Sacrey et al., 2014), and poor manual dexterity and coordination (Kindregan, Gallagher, & Gormley, 2015; Kushki, Chau, & Anagnostou, 2011). Evidence gathered in recent research suggests that motor impairments are not only co-occurring neurological symptoms but may be one of the earliest identifiable and most prevalent features of autism (Bo et al., 2016; Dziuk et al., 2007; Hilton et al., 2007, 2012; Ming, Brimacombe, & Wagner, 2007).

Motor development is closely intertwined with socio-emotional and cognitive development (Jones, Gliga, Bedford, Charman, & Johnson, 2014; Leonard & Hill, 2014). Recent studies have demonstrated that early motor impairments are strong predictors of social communication deficits developed later in childhood. For instance, oral and manual motor impairments in infancy and toddlerhood have been linked to later communication delays (Bhat, Galloway, & Landa, 2012; Flanagan et al., 2012; Libertus et al., 2014), speech fluency deficits (Gernsbacher et al., 2008), and difficulties in processing emotional facial expressions (Leonard et al., 2015; Leonard & Hill, 2014).

There is also increasing evidence that motor control is deeply implicated in social cognition (Mostofsky & Ewen, 2011). Social skills depend on one's performance of skilled and goal-oriented movements (praxis) as well as the understanding of other's movements and associated intentions. Through observation and imitation of other's actions, one builds internal representations that are used as template to interpret and predict other people's intentions (Mostofsky & Ewen, 2011). Researchers have found that dyspraxia (i.e., a developmental impairment in the planning, execution, and recognition of learned skilled movements or goal-oriented motor activities) is correlated with core social, communicative, and behavioral features of autism (Dowell, Mahone, & Mostofsky, 2009; Dziuk et al., 2007). The correlation between abnormal praxis development with social/communicative impairments in ASD suggests that "similar mechanisms may underlie impaired development and execution of both motor skills and social/communicative skills in autism" (Mostofsky & Ewen, 2011, p. 439). Additionally, new analyses methods have recently emerged allowing examination of micro-movements (Torres et al., 2013; Torres & Denisova, 2016). Torres and colleagues suggested that deficits in micro-movements are associated with difficulties in building internal representations of one's own movements, which in turn can affect the interpretation and prediction of other people's intentions.

Collectively, this growing body of research evidence indicates that motor control deficits may be directly implicated in social, emotional, and communication impairments in ASD. However, motor deficits are generally not addressed as a primary target of intervention for autism. Therefore, clinical research is needed to understand the feasibility and impact of interventions, including music therapy, to address motor deficits in ASD.

Neurologic Music Therapy Interventions for Motor Control Impairment

Neurologic Music Therapy techniques, such as Rhythmic Auditory Stimulation (RAS), have been successfully applied in motor rehabilitation (Thaut & Abiru, 2010; Thaut et al., 2015; Thaut & Hoemberg, 2014). RAS uses rhythmic cuing (e.g., metronome or music) to facilitate the rehabilitation of movements that are intrinsically rhythmic. Several clinical studies have demonstrated that rhythmic auditory cues have immediate effects on gait speed, stride length, improving gait symmetry and stability (Arias & Cudeiro, 2010; Kwak, 2007; McIntosh et al., 1997; Thaut, McIntosh, & Rice, 1997; Thaut et al., 1996, 1999). It has also been shown that rhythm enhances upper limb control by improving spatiotemporal control, movement variability and reaching trajectories, and reducing reliance on compensatory movements (Malcolm, Massie, & Thaut, 2009; Thaut, Kenyon, Hurt, McIntosh, & Hoemberg, 2002). Moreover, it has been shown that rhythm-based interventions can drive cortical plasticity by promoting structural and functional connectivity changes in the brain (Luft et al., 2004; Whitall et al., 2000).

Other rhythm-based techniques in Neurologic Music Therapy that have been well-established in motor rehabilitation are Patterned Sensory Enhancement (PSE) and Therapeutic Instrumental Music Performance (TIMP) (Thaut & Hoemberg, 2014). PSE uses highly structured musical patterns to stimulate and facilitate patterned information processing that regulates and enhances the specific spatial, force, and temporal aspects of complex movements (e.g., Malcolm et al., 2009;

Thaut et al., 2002; Wang et al., 2013). TIMP utilizes musical instruments to (re)train functional movements skills, targeting range of motion, endurance, finger dexterity, limb coordination, and functional hand movements (e.g., Altenmüller et al., 2009; Peng et al., 2011; Schneider et al., 2007).

The use of rhythm in movement rehabilitation is based on extensive research demonstrating neural entrainment between auditory and motor systems (for review, see Thaut et al., 2015). The auditory system is well-known for its ability to detect temporal patterns in auditory signals with extreme precision and rapidly construct stable temporal templates (for review, see Thaut & Kenyon, 2003). The auditory system has richly distributed fiber connections to motor centers from the spinal cord upward on brain stem, subcortical, and cortical levels (Felix et al., 2011; Koziol & Budding, 2009; Schmahmann & Pandya, 1995). Auditory-motor entrainment occurs when the firing rates of auditory neurons, triggered by auditory rhythm and music, entrain the firing patterns of motor neurons. The clinical importance of auditory-motor entrainment is that the continuous time reference provided by the rhythm of the music primes the motor system in a state of readiness by providing predictable time cues that allow movement anticipation and motor planning based on foreknowledge of the duration of the cue period, hence increasing response quality (Thaut et al., 2015; Thaut & Hoemberg, 2014).

One of the subcortical areas that receives auditory projections is the cerebellum. The cerebellum is deeply involved in sensorimotor synchronization due to its key role in the coordination and fine-tuning of movements by feedforward prediction of the timing of an upcoming movement, and by integrating sensory and motor feedback information to modify and correct subsequent movements (Bastian, 2006; Diedrichsen, Criscimagna-Hemminger, & Shadmehr, 2007; Grahn, 2012; Ivry & Spencer, 2004; Thaut, 2003). The cerebellum has also been implicated in different temporal tasks, such as retrieving rhythmic information (Konoike et al., 2012) and tracking changes in rhythmic interval duration. Interestingly, abnormalities in the cerebellum (Allen, Müller, & Courchesne, 2004; Becker & Stoodley, 2013; Chukoskie, Townsend, & Westerfield, 2013; D'Mello & Stoodley, 2015; Fatemi et al., 2012; Koziol et al., 2014; Wang et al., 2014) and impaired functional connectivity (Belmonte, 2004; Mostofsky & Ewen, 2011; Mostofsky et al., 2009) are among the most consistently reported structural and functional brain abnormalities in autism. The cerebellum is interconnected with several different regions of the cerebral cortex, including areas involved in attention (Allen et al., 1997; Courchesne et al., 1994; Murphy et al., 2014), language (Hodge et al., 2010), social processing (Jack & Pelphrey, 2015; Sokolov et al., 2012), and executive function (Gilbert et al., 2008; Koziol et al., 2014). This extensive connectivity provides anatomical substrate by which dysfunctional cerebro-cerebellar connectivity could be involved in the large spectrum of symptoms that comprise ASD (D'Mello & Stoodley, 2015; Mostofsky & Ewen, 2011).

Given the nature of the motor impairments displayed by children with autism and the strong body of clinical research demonstrating the effectiveness of rhythmic-based music intervention to improve motor functioning, it is crucial investigating whether the aforementioned Neurologic Music Therapy techniques can be effective to improve motor control skills in individuals with ASD. Moreover, recent research shows that rhythm synchronization skills are preserved in ASD over the course of childhood development (Tryfon et al., 2017), which supports the use of rhythm- and music-based interventions in this population.

Attention Deficits in ASD

Cognitive deficits are also widely observed in ASD, although these deficits are generally regarded as secondary impairments or comorbidities. However, new research suggests a reconsideration of attention dysfunction in ASD as primary impairment, potentially underlying other impairments in language and socio-emotional areas. Attention is critically involved in all cognitive functions as the gateway to voluntary control of thoughts, emotions, and actions (Fan, 2013: 281). There is accumulating evidence from behavioral and neuroimaging studies that individuals with ASD display a wide range of attentional deficits across the many domains of attention functions (for review see Allen & Courchesne, 2001). Abnormal spatial orientation of attention has been extensively reported in autism literature. Researchers have reported, for instance, that individuals with autism have a limited capacity in disengaging and moving attention from a stimulus or task to another (Landry & Bryson, 2004; Wainwright-Sharp & Bryson, 1993). Orientation deficits have also been observed in tasks involving rapid shifting of attention between sensory modalities (Courchesne et al., 1994), between object features (Rinehart et al., 2001), and between spatial locations (Townsend, Harris, & Courchesne, 1996). Orientation to human faces and social information have also been well-studied in ASD. Evidence suggests that individuals with autism have particular difficulty attending to and processing social stimuli (e.g., facial expressions, gestures) (Dawson et al., 1998; Jones & Klin, 2013). Orientation and executive control functions of attention are essential during the normal exchange of information and turn-taking, which happens rapidly, frequently, and often unpredictably (Fan, 2013). Additionally, Selective attention deficits in individuals with autism have been demonstrated in tasks where the targets are defined by different shapes or colors (Allen & Courchesne, 2001, 2003) or on tasks including competing distractors (Belmonte & Yurgelun-Todd, 2003; Burack, 1994). Impaired ability to filter task-irrelevant information and control shifts of attention may be directly associated with a variety of commonly observed autistic features, such as stimulus overselectivity, perseveration, and narrowed interests (Courchesne et al., 1994).

Studies have also found that children at risk and with ASD display significant impairments in initiating and responding to joint attention already by the age of 14–18 months (Goldberg et al., 2005; Stone et al., 2007; Sullivan et al., 2007). Infant-initiated joint attention, or directing attention, refers to a child's use of gestures, gaze shifts, pointing, and other cues to initiate a shared experience with others; whereas responding to joint attention, or attention following, reflects the infant's ability to orient attention in response to a cue, such as someone's gaze, head turn, point, or attention-directing utterance. Sullivan et al. (2007) examined response to joint attention (RJA) in children at risk of developing ASD at 14 months and 24 months of age and found that 14-month-olds at risk already displayed significant deficits in responding to gaze shift cues and/or pointing cues. At 24 months of age, children at risk completely failed to respond to any RJA opportunity, which indicated that there was little developmental improvement in response behaviors in the ASD group between 14 and 24 months. The authors concluded that response to joint attention performance predicted later receptive and expressive language performance, and reliably predicted later ASD diagnosis.

As previously discussed, joint attention impairments have been recently investigated in music therapy research (Kim et al., 2008; LaGasse, 2014). However, there is a paucity of studies investigating the effects of music-based intervention on other attention domains.

Neurologic Music Therapy Intervention for Attention Deficits

Musical Attention Control Training (MACT) is a Neurologic Music Therapy technique that applies structured musical exercises to train attention function (Thaut & Hoemberg, 2014). MACT activities involve, for instance, predefined musical/verbal cues to which the child has to respond by making musical adjustments, such as changing instruments or changing in pitch register or tempo, thus actively training functions such as sustained, selective, or divided attention (e.g., Knox et al., 2003; Pasiali, LaGasse, & Penn, 2014).

Rhythmic entrainment in music extends beyond motor control (for review, see Thaut, 2010). Music is inherently temporal and sequential, and the regularity of rhythmic pulses generates temporal expectations that allow us to predict when the next beat of the music will occur and consequently direct our attention to a particular moment in time (Honing, Bouwer, & Háden, 2014; Large & Palmer, 2002). There is a large and consistent body of research demonstrating that rhythm is key in tuning and modulating attention (Drake, Jones, & Baruch, 2000; Jones, 1992; Jones, Boltz, & Kidd, 1982). According to the dynamic attending theory (Large & Jones, 1999), internal fluctuations in attentional energy (attending rhythms) entrain with the temporal patterns of external events, thus generating expectations about when future events will occur. Consequently, if an event coincides with this attention peak, its processing is facilitated. There is extensive evidence showing, for instance, that people are most accurate in judging pitch changes and time intervals that occur on the beat of the music than at unexpected time points (Honing et al., 2014; Jones, 1992; Lange, 2010).

Music also engages different attention domains. For example, when listening to an orchestra, it is relatively easy to focus attention selectively to one group of instruments or divide attention between multiple simultaneous melodic lines (Bonnel et al., 2001; Fujioka et al., 2005; Johnson & Zatorre, 2006; Maidhof & Koelsch, 2011). Studies have shown that the capacity to focus attention on relevant stimuli while ignoring distracting information is possible given to an anticipatory attentional mechanism that suppresses the processing of distracting information (Fu et al., 2001; Johnson & Zatorre, 2005). It is possible, therefore, that the rhythmic structure of the music modulates anticipatory mechanisms facilitating the process of attentionally relevant information.

Of considerable importance may also be recently emerging electrophysiological and behavioral evidence that auditory rhythmic cues can entrain visual attention (Escoffier, Herrmann, & Schirmer, 2015; Miller, Carlson, & McAuley, 2013; Sacrey, Clark, & Whishaw, 2009). Research has shown that multisensory (auditory-visual) temporal integration is impaired in autism; hence an investigation may be warranted whether music-based audiovisual integration training may improve temporal functions in multisensory binding for children with ASD (Brandwein et al., 2014; Lee & Noppeney, 2011; Stevenson et al., 2014).

Other evidence in favor of using music as intervention for attention deficits is that music, like other higher cognitive tasks, requires the activation of different cortical and subcortical regions in an organized and synchronized way. Listening to rhythmic sequences such as music increases connectivity in extensive reciprocal cortico-subcortical projections (Bhattacharya & Petsche, 2005; Ohnishi et al., 2001) and induces cortico-cortical coherence in auditory and motor areas (Fujioka et al., 2012; Nozaradan, 2014). Studies have also demonstrated that engaging in active music-making increases connectivity in the sensorimotor cortex (Lee & Noppeney, 2011; Pascual-Leone, 2001) and induces cortical plasticity in several brain regions, including those areas involved in motor control and optimizing the acquisition of sensory information, such as the superior temporal sulcus-premotor-cerebellar circuitry (Luft et al., 2004; Schlaug et al., 2005).

Based on this robust scientific evidence of the influence of music on attention functions, a recent study was conducted with high-functioning adolescents with autism to investigate the effectiveness of Musical Attention Control Training (MACT) to improve attention functioning (Pasiali et al., 2014). The study found significant improvement in measures of selective attention and attentional control after eight intervention sessions. This promising result is based on a small sample and relatively short intervention period, encouraging replication in larger controlled trials. Nonetheless, this study suggests that music-based therapy can be a potential tool to address attention function in individuals with ASD.

Conclusion

The growing body of literature reviewed in this chapter indicates that the potential of music-based therapy for ASD is yet to be fully explored. Music-related skills in domains such as memory, auditory perception, emotion and language are greatly preserved in ASD. Moreover, there is robust evidence from basic neuroimaging and correlational research demonstrating a meaningful link between musical behavior and non-musical function, supporting the therapeutic use of music in the development of speech, language, social behavior, emotion, motor and attention skills. However, while the empirical foundation for the relevance of music as therapy for ASD has grown significantly over the past decades, there is still limited high-quality clinical research in music therapy for ASD. The current state of clinical research indicates that music therapy may be as effective as standard speech interventions to address speech production deficits, and that music could be used to facilitate emotional understanding in children with ASD. Studies also provide promising indications for music-based intervention to address social communication skills, particularly, joint attention behaviors. Based on a neuroscience-driven understanding of brain and behavior function in ASD - especially in lieu of converging evidence regarding dysfunctions in cortico-cerebellar networks and neural network connectivity – we presented new directions for the use of music-based therapy for ASD. We argued that music therapy may effectively address previously under-researched functions such as attention and motor control, and significantly benefit the neurodevelopment of individuals with ASD. A new emphasis has emerged in the clinical neuroscience of music focusing on research and evidence-based practice, and Neurologic Music Therapy is an example of the recent shift to a neuroscience model of clinical and research practice. We hope that the evidence provided here ignites further research to better understand the potential impact of music-based therapy to the healthy neurodevelopment of persons with ASD.

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