

FOCUS REVIEW

Autism, Emotion Recognition and the Mirror Neuron System: The Case of Music

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ABSTRACT: Understanding emotions is fundamental to our ability to navigate and thrive in a complex world of human social interaction. Individuals with Autism Spectrum Disorders (ASD) are known to experience difficulties with the communication and understanding of emotion, such as the nonverbal expression of emotion and the interpretation of emotions of others from facial expressions and body language. These deficits often lead to loneliness and isolation from peers, and social withdrawal from the environment in general. In the case of music however, there is evidence to suggest that individuals with ASD do not have difficulties recognizing simple emotions. In addition, individuals with ASD have been found to show normal and even superior abilities with specific aspects of music processing, and often show strong preferences towards music. It is possible these varying abilities with different types of expressive communication may be related to a neural system referred to as the mirror neuron system (MNS), which has been proposed as deficient in individuals with autism. Music's power to stimulate emotions and intensify our social experiences might activate the MNS in individuals with ASD, and thus provide a neural foundation for music as an effective therapeutic tool. In this review, we present literature on the ontogeny of emotion processing in typical development and in individuals with ASD, with a focus on the case of music.

KEYWORDS: limbic system, mirror neurons, music, autism, social interaction

INTRODUCTION

The processing of affect underpins human experience and serves as the foundation of human interactions in everyday life. This complex process involves the ability to perceive, understand, and respond appropriately to emotional cues. The accurate understanding of these emotional cues is crucial in the assessment of threat, in negotiating transactions, and in the formation of social bonds (1-4).

Autism Spectrum Disorders (ASD) is an umbrella term often used to describe a continuum of diagnoses that include Autistic Disorder, Asperger's Disorder, and

Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS). Collectively, ASD is characterized by deficits in communication, impairments in social interactions, and restricted and repetitive patterns of behavior (5). One of the core deficits in individuals with ASD is a deficit in emotion processing and communication that prevents them from achieving successful reciprocal social interactions. Laushey and Heflin (2000) have proposed that the most profound and defining issues for individuals with ASD are those difficulties related to poor social functioning (6). Specific social deficits among individuals with ASD often include difficulties in expressing emotions, understanding the emotions of others, and empathizing (7-11), as well as the inability to interpret social cues, assess the formality of social events, and act accordingly (12). The inability to understand the emotional expressions of others and respond appropriately hinders the development of meaningful interpersonal relationships. As a result, individuals with ASD who lack the ability to successfully interpret

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emotional cues are at risk for social rejection. In fact, children with ASD often report poorer quality friendships, including more loneliness, less companionship and less help from their friends (13). Thus, the ramifications of emotion processing difficulties frequently include both emotional and physical isolation.

Deficits in the ability to understand and interpret emotional stimuli among individuals with ASD provides a unique and important opportunity for the study of emotion processing, both for clinical and typically developing populations. In fact, the processing of bodily expressions of emotion has been widely studied in individuals with ASD (14, 15). However, musical emotion processing in ASD has received very little research attention, despite the fact that individuals with ASD seem to respond so positively to music (16). The purpose of this review is to examine studies of emotion processing in typical development and in individuals with ASD, with a focus on music perception and how it may affect the functioning of the mirror neuron system (MNS) in individuals with autism. Our ultimate aim is to evaluate the potential role of music in the study and treatment of socio-emotional deficits in individuals with ASD and highlight the need for studies of musical emotion processing, which may hold a promising key to the development of novel, music-based therapeutic interventions.

Typical Development of Emotion Processing

Perhaps the most fundamental level of social reciprocity is the ability to be in a relationship, which is founded upon the critical component of emotional attunement. The importance of affect exchange is evident from the earliest days of life, when social reciprocity begins with affect sharing and coordination with the caregiver. Trevarthen and Aitken (1994) have proposed that there is an "intrinsic motive formation" that acts as the foundation for the infant's adaptation to her/his environment. This pattern of neural activity works to "direct the infant's brain emotionally" as they self-regulate and try to understand the feelings of others (17). These early exchanges of affect between caregivers and infants lay the foundation for the development of more complex types of communication later in life (18).

Affective exchanges begin almost immediately after birth. Emotional attunement in typically developing children is documented as early as nine minutes of age, where infants preferentially attend to a face-like stimulus (19), and demonstrate a preference for their mother's voice at birth (20). Infants as early as two to three months of age begin to discriminate between several different affective expressions shown by their

parents (20). At five months, infants are developing the ability to read affect in the faces of strangers and at six months are able to emotionally attune to their caregivers (21).

Arguably, the foundation for emotional attunement and complex social interactions is dependent upon the emergence and development of joint attention. Joint attention is defined as "the ability to coordinate interest in external objects or events with other people" (22), and is thought to be an attempt to share the experience of objects and events with others (23). Among typically developing infants, the ability for joint attention emerges between 9 and 15 months (24). This is when the infant learns to use gaze to direct the attention of others to objects of interest (25). An inherent interest in other people appears to provide the motivation for some of the behavior that leads to learning to share and track gaze (26-29). Imitative behavior also becomes more prevalent, precise and object-directed at this time. For example, infants will typically imitate the ways in which adults manipulate objects (30).

Studies have shown that beginning in early infancy, typically developing infants begin to use social referencing to make sense of confusing or threatening situations or persons, by looking at the face of their caregiver for information (31, 32). Such behaviors that emerge around nine months and continue to develop into the third year of life increase the infants' understanding of self and others as intentional agents, and are based in the gradual development of theory of mind (33). Theory of Mind (ToM) is the ability to understand the desires, intentions, and knowledge of another (34). Typically developing children generally show evidence of a ToM around age four as they begin to understand the perspectives of other persons (35). However, based upon a study examining non-verbal looking time using the violation-of-expectation method, it has been argued that the emergence of a ToM with an implicit understanding of beliefs may even begin to develop as early as 15 months (36). In examining precursors to ToM, Sodian and Thoermer (2008) show that children under the age of three have the ability to use their own and others' epistemic states in communication when engaging in false-belief tasks (37). As children continue to grow, their ability to read affective cues and socially reciprocate becomes more refined. The gradual acquisition of such knowledge allows one to be part of and function successfully in a given culture, by incorporating others' perspectives into one's own mind through cultural learning (33).

Development of Emotion Processing in ASD

Compared to typically developing children, the developmental trajectory of affect attunement is very

different among infants with ASD. Even in infancy, children with ASD fail to show the typical interest in human faces, instead showing a preference for inanimate objects (38-41). The automatic mirroring of affective gestures and expressions is also considerably weaker in infants with ASD (42-44). Consequences related to these deficits are displayed during infancy, and extend throughout childhood development. Children with ASD tend to pay less attention to the negative emotions of others compared to typically developing children (45-47). They also appear to have more negative affective exchanges (48), and display less positive emotion to their social partner (49, 50) when compared to typically developing peers. The lack of attention paid to emotional cues often causes a rift in social interactions as well as lowering the affective responsiveness of children with ASD. Emotional reciprocity is fundamental to the development of social skills and successful social interactions. Due to the combination of deficits exhibited by children with ASD in this realm, their socio-emotional development is frequently stilted.

Deficits in joint attention among individuals with autism are well-documented (51-53). Mundy, Sigman and Kasari (1994) found that joint attention for children with ASD was lower than developmentally delayed and typically developing children (24). In a more recent study, Naber and colleagues (2007) examined different types of joint attention, including basic, associated, and visual. At 24 months, children with ASD showed significantly less overall joint attention correlated with characteristics of autism and developmental level, but at 42 months the associations disappeared. Of the three types of joint attention, only joint visual attention was less at 42 months, suggesting that joint visual attention may be the distinct deficit of concern in the development of joint attention in children with ASD (54).

In research on gaze behavior it has been found that, compared to typically developing children, young children with ASD shift attention between an object and another object more often than between a person and object or between person and person (55). Furthermore, children with ASD spend less time looking at people and more time looking at objects, compared to neurotypical children (55). By contrast, the processing of cartoons with human figures does not show any difference between typically developing children and children with ASD (56). In a study by Klin and colleagues (2002), it was found that when looking at faces, adults with ASD looked at the eyes only half the time of neurotypical adults, but twice as often at mouths and objects (57). A recent neuroimaging study found that brain responses to non-social stimuli (houses) were

modulated by attention, both in adults with ASD and a matched control group, but only the control participants demonstrated attentional modulation of face-selective regions during viewing of social (face) stimuli (58). Thus, the participants with ASD demonstrated a lack of attentional modulation for the social stimulus. Taken together, these findings suggest that atypical gaze patterns in individuals with ASD may be related to the reduced salience of social stimuli from the earliest days of life, a deficit that persists into adulthood. Indeed, reduced visual attention to socially salient stimuli may underpin many of the social communication impairments seen in individuals with ASD.

While typically developing infants use social referencing to make sense of confusing or threatening situations (32), children with ASD are less likely to reference another person in these same instances (59) - they are unlikely to voluntarily share their experience with others, and avoid initiating triadic interactions, even when guided to do so (60). However, these atypical social behaviors in children with ASD have been suggested to be secondary to impairments in the ability to represent mental states of others, or ToM (61). Normal intellectual and verbal abilities appear to lessen the impact of earlier impairment in ToM, such that in structured situations, individuals with ASD may actually demonstrate ToM abilities (62, 63). ToM has been studied in relation to several other aspects of ASD, including how individuals with ASD are less likely to utilize ToM to spontaneously attribute meaning (64), in relation to weak central coherence and event schemas (65), and executive function (66). Taken together, these studies do point to consistent deficits in various aspects of ToM in individuals with ASD.

Social empathy is another area of research that has been widely investigated and related to atypical social interactions among individuals with ASD. Arguably, one of the first steps in social competency is the ability to be empathic. Consequently, when empathy is absent or impaired, social interactions are hindered. Empathy can be categorized into two principle areas: cognitive empathy, which is the process by which one understands another's perspective, and is related to ToM (67), and emotional empathy, which is defined as an emotional response to another's emotional display (67, 68). While some children with high-functioning ASD may have more advanced ToM capabilities (i.e., cognitive empathy), the impairments in identifying emotions in others are still thought to be present (69). Specific deficits in empathy-related processes include the understanding of emotional stimuli, inter-subjectivity, and reflecting of affect (70-73), all of which, when deficient have the capacity to negatively impact social reciprocity. Hence, the deficit in

emotional empathy in individuals with ASD may greatly impede social functioning.

Consequences of Emotional Isolation in ASD

For individuals with ASD, difficulties in emotion processing are compounded by the inability to accurately perceive and understand emotional cues. The implications of such deficits are many, not the least of which are emotional and physical isolation from family, peers and community. Impairments in social functioning and the inability to understand emotion also commonly result in peer rejection and poor social support; often producing higher levels of loneliness and poor quality of friendships for children with ASD, in comparison to typically developing peers (13, 74). On self-report measures of friendship quality, children with ASD endorse less security and trust in friendships, lower levels of companionship, and less helpfulness from friends (13). While loneliness and understanding of friendship are closely linked for typically developing children, Bauminger and Kasari (2000) hypothesize that high-functioning children with ASD may lack the “affective glue” to understand how to utilize their understanding of friendship to reduce loneliness. Thus, the lack of affective bonding between children with ASD and their peers limits the ability to initiate and maintain relationships.

Similarly, many adolescents and adults with ASD also lack close friendships compared to typically developing peers (75). Possibly due to a rise in the complexity of social cues and a greater need for understanding of emotion processing that accompanies developmental maturity, social deficits often become even more prominent as children with ASD enter adolescence (76) and adulthood (77). Although certain symptom aspects of ASD may improve with time and intervention, social difficulties often related to the comprehension of emotions, seem to persist throughout the individual’s lifespan and may represent a more chronic deficit in autism (11, 78). As adults, the lack of community connections and friendships that are often taken for granted by typically developing persons (75) may contribute to higher rates of depression, anxiety (79), and victimization among individuals with ASD (80). Thus, identifying and developing interventions to improve socio-emotional functioning that are of most help to individuals with ASD is extremely important.

The Mirror Neuron System and Emotion Processing

In typical development, the sensation that we possess a kind of immediate understanding of what others are doing or feeling is so pervasive and automatic, that we rarely think about it. In fact, this connectedness often allows us to feel others’ emotions, as if they were our

own. Recently, neuroscience has provided a possible neural mechanism for this matching of sensory information to our own internal representations in the discovery of the mirror neuron system. Researchers working with monkeys, discovered individual neurons in the macaque brain that fire both when an action is executed and when that same action is observed or heard (81), leading these neurons to be called ‘mirror neurons’, based on this unique functional property. Fadiga and colleagues (1995) provided the first demonstration of a neural system for coding the correspondence between observed and executed actions in humans using single-pulse transcranial magnetic stimulation (TMS). Subsequent work then confirmed these findings, leading researchers to conclude that also in humans, there is a motor resonance system resembling the one described in the monkey (82-86). These data – showing that we use the same neural resources to represent the actions and emotions of others, as our own – provide evidence for a neural substrate that can parsimoniously explain our intuitive ‘feeling’ of effortlessly understanding others’ actions and emotions. Using functional Magnetic Resonance Imaging (fMRI) to localize brain regions showing mirror properties, Iacoboni and colleagues (1999) hypothesized that imitation, which contains both an observation and execution component would lead to a BOLD (blood-oxygen-level dependent; and indirect measure of neural activity) signal increase greater than either action observation or execution alone. This study found two cortical areas that showed this predicted pattern of activity, the posterior inferior frontal gyrus (pIFG) and the rostral sector of the inferior parietal lobule (IPL) (87). Thus, mirror resonance mechanisms subserved by the fronto-parietal MNS are involved in action perception and performance, meaning that this neural system is recruited during both the execution of our own actions, and the observation of the actions of others. Our ability to understand others’ actions and emotions, may thus be based in our ability to ‘resonate’ with others on a motor level, a function that may in fact ground our ability to know about other minds (88).

Although still in its early stages of study, the MNS in humans has already been associated with a wide variety of higher-level functions in addition to action representation, including imitation and imitation learning (87, 89-91), intention understanding (92, 93), empathy and ToM (94-96), self-representation (97-99), and the evolution of language (100, 101). These, and subsequent studies of the human MNS, have greatly contributed to our understanding of the neural bases of perception-action mechanisms, social communication and emotion (81, 102, 103). Interestingly, these cognitive functions subserved at least in part by the

MNS - including imitation (96, 104), empathy and ToM (104, 105), self-representation (105) and language (106) - have all been implicated as deficient in autism. In fact, dysfunction of the MNS has been proposed as a possible cause of autism (96, 107-109).

Due to its importance in imitation, a dysfunction in the MNS may lead to a failure to develop reciprocal social abilities including shared/joint attention, empathy and ToM, as well as gestural recognition and language (96). Deficits in imitation during early childhood development may be at the root of many of the social deficits that manifest themselves during the later development of patients with autism (110). The fundamental similarity between imitation and attribution of mental states is that both processes involve translating from the perspective of another individual to oneself. In belief attribution, one creates a representation of the other person's representation of the world in one's own brain, while the same process occurs during imitation with an action plan originating from another person being translated to one's own frame of reference (111). Autism-specific deficits in imitation have consistently been found (44, 112). The errors in imitation of patients with ASD, seem to suggest that they have a deficit in the basic ability of translating action plans from the perspective of others to themselves (111). Differences in emotion processing between typically developing individuals and their peers with ASD are also observable at a neural level. A recent neuroimaging study investigating imitation of emotional facial expressions has shown that children with autism have virtually no activity within the MNS compared to typically developing controls, clearly linking their social isolation to a neural system important for understanding the intentions, actions, and emotions of others (113). Thus, the MNS offers a potential neural substrate for understanding the social difficulties encountered by individuals with ASD, while somewhat paradoxically, the MNS may also offer a neural correlate for the special appreciation of music shown by individuals with ASD.

Music Processing and ASD

In contrast to the wealth of studies on emotion processing from body gestures and facial expressions of others, emotion processing in music is a relatively new area of research. Music, like facial expressions, can convey emotions, and the ability to enjoy music is a universal human trait – humans tend to relate to music spontaneously and effortlessly. Music also has the powerful ability to stimulate emotions, trigger memories, and intensify our social experiences. Research in the psychology of music has begun to emphasize the intensely social nature of musical

activities (114), which may even hold the key to music's potential as a therapeutic and educational tool (115).

In fact, the last decade has seen an explosion of scientific research into the neural basis of music, revealing that different aspects of musical processing recruit almost all regions of the brain—including prefrontal cortex, premotor cortex, motor cortex, somatosensory cortex, temporal lobes, parietal cortex, occipital cortex, cerebellum, and limbic regions including the amygdala and thalamus—unlike any other stimulus or cognitive process (116-119). It has also been shown that components of the limbic system involved in processing emotional stimuli in general – the amygdala, the nucleus accumbens (NA), the hypothalamus, the orbitofrontal cortex (OFC), the ventromedial prefrontal cortex (VMPFC), the anterior cingulate cortex (ACC) and the anterior insula (AI) - are also involved during the experience of both pleasant and unpleasant music (120-125). This shows a neural overlap between emotion processing of non-musical stimuli (e.g. pictures, faces) and musical stimuli.

In the classic paper first describing autism, Leo Kanner (1943) presented eleven case studies of children with autism and repeatedly mentioned musical abilities and musical interest in six of the children (126). Since then, researchers have systematically studied the musical processing abilities of individuals with autism, and have shown that while language abilities may be deficient; individuals with ASD seem to process music in similar ways to typically developing individuals (127, 128). Moreover, individuals with ASD appear to show a spontaneous preference for musical over verbal stimuli (129), and it has been reported that approximately 40% of individuals within this population express a special interest in music (130). These reports of prevalent interest in music within the ASD population suggest that musical appreciation may be unimpaired in ASD, and may even represent a particular ability area (126, 131). For example, Applebaum and colleagues (1979) compared three musically naïve children with ASD and three typically developing musically experienced children on their ability to sing back musical stimuli. They found that children with autism performed as well or better than the musically experienced controls (132). Furthermore, a number of studies have indicated that individuals with ASD show superior pitch abilities. For example, Heaton and colleagues (1998) found that children with ASD performed better than control children on a pitch memory task, while performing equally well on a speech sound memory task. In fact, children with autism remembered more tone/picture pairs one week after initial exposure than controls did after 2.5 minutes (133)! More recently, Heaton (2003) found that children with high-functioning autism

showed enhanced pitch memory and labeling (130). In studies of pitch discrimination, individuals with high-functioning autism were superior to the comparison group, showing enhanced perception of local pitches (134) and exhibiting an increased sensitivity to pitch on both discrimination and categorization tasks (135).

Individuals with ASD not only show exceptional abilities in the domain of musical processing abilities, but research suggests that affective qualities of music might also be understood by this population. Heaton and colleagues (1999) demonstrated that children with ASD do not differ from typically-developing controls in their ability to perceive happy and sad affect in musical excerpts (127). In a recent follow-up study, it was shown that active music listening is characteristic of children with autism, and that this listening results in the acquisition of culturally embedded knowledge about musical meaning. Based on their findings, the authors conclude that emotion-processing in music may be preserved, and may be closely related to the level of language development, rather than ASD diagnosis (128). This apparently spared ability to understand the affective qualities of music is in marked contrast with the general difficulties in emotional communication and interpretation experienced by individuals with ASD in other domains, such as in social communication (136, 137).

Shared Affective Motion Experience (SAME) – A Mirror Neuron System-Based Model of Music Perception

How does the brain perceive music? How does emotional music affect the brain of individuals with ASD? Bridging recent neuroimaging findings on the neural bases of intention understanding, action perception and social communication (90, 93, 138, 139) with findings on the neural bases of music perception, it has been proposed that interactions between the MNS and the limbic system may allow the human brain to ‘understand’ complex patterns of musical signals and provide a neural substrate for the subsequent emotional response (115, 140).

The Shared Affective Motion Experience (SAME) model of music perception holds that music is perceived not only as an auditory signal, but also as intentional, hierarchically organized sequences of expressive motor acts behind the signal; and that the MNS allows for co-representation and sharing of a musical experience between agent and listener. Musical sounds are imbued with intentional expression, evoking the sense of an intentional agent, and leading to the sense of a shared experience in the listener. Within a neural network involving the temporal cortex, the fronto-parietal MNS, and the limbic system, auditory features of the musical signal are processed primarily in the superior temporal

gyrus and are combined with structural features of the expressive motion information within the MNS. The anterior insula forms a neural conduit between the MNS and the limbic system (94), allowing incoming information to be evaluated in relation to the perceiver’s autonomic and emotional state, thus leading to a complex emotional response to the music. The recruitment of these neural systems in both the agent (musician) and the listener allows for a shared affective motion experience (SAME) (115). As a result, the expressive dynamics of heard sound gestures can be interpreted in terms of the expressive dynamics of personal vocal and physical gestures (115, 140).

It might appear puzzling that children with ASD seem to have deficits in the functioning of their MNS, yet are able to experience some of the affective qualities of music. However, it is known that children with ASD are particularly drawn to abstract patterns, and the repetitive, predictable nature of musical sounds may fulfill such a role. It is also possible that through experience and familiarity with these patterns, or indeed through shared musical imitation and synchronization activities, the MNS may become sufficiently engaged for children with ASD to move from the appreciation of musical sound patterns to the appreciation of the emotional state of the agent making them; an agent who appears to behave in predictable, familiar ways that are comforting and companionable, rather than confusing. While the social world with its lack of predictability is often confusing and even frightening for the individual with ASD, the predictable patterns typically found in musical stimuli may provide a reassuring and foreseeable avenue for emotion processing. It may also be highly relevant that music is dependent on auditory processing, since this might allow for attention to the socially salient information, whereas such socially salient information presented visually has been reported as unrewarding (49) and in some cases aversive (141) for individuals with ASD.

During the early development of music as a therapeutic tool, Alvin (1975) and Nordoff and Robbins (1977) (142-144) referred to musical attunement being achieved between the therapist and the child – the therapist would ‘meet the child’ in music, and through this subtle, rhythmic interaction, communication was facilitated. It is within and through this shared, affective, musical experience that music therapy may have its greatest beneficial effect on socio-emotional behaviors. Accordingly, decades of music therapy research have indicated that autistic children do respond well to music therapy (142, 145), as music facilitates and supports their desire to communicate (146, 147). Trevarthen (2000) has proposed that the use of music therapy with autistic children may help improve their

socio-emotional communication abilities, by helping them to develop timing and motor skills. Brownell (2002) has also found that the use of musically adapted storytelling is an effective and viable treatment option for modifying target behaviors of children with autism (148).

While typically developing children often learn basic social rules and emotion processing through observation and imitation of peer behavior and/or specific instruction from caregivers (149, 150), children with ASD often require further instruction. Learning to navigate the social world is particularly challenging for persons with ASD, since the natural development and transmission of necessary emotion processing and understanding of social cues requires generally positive and sustained interaction with others. Initiating and sustaining joint attention, which is often absent in children with ASD, is a primary therapeutic goal of music therapy. The SAME model proposes that by creating the feeling of 'being together' - by jointly attending to music through imitation, synchronization, and shared affective experience - these powerful components of musical experience may be key aspects of therapeutic and educational intervention activities for individuals with ASD (115).

Several reviews of the literature have reported consistent and significant improvements in communicative behavior and emotional responsiveness by means of music interventions in individuals with ASD (151-153). While the nature of the musical interventions in individual studies is heterogeneous, a recent meta-analysis of ten studies comparing music to no-music conditions in the treatment of children and adolescents with autism, found an overall effect size of $d = 0.77$, indicating a significant benefit of music intervention. Some of the areas of improvement included: increased appropriate social behaviors and decreased inappropriate, stereotypical, and self-stimulatory behaviors; increased verbalizations, gestures, and comprehension; and increased communicative acts and engagement with others, among other positive effects (152). As the above evidence illustrates, children with ASD may benefit in particular from shared musical experience, as it offers opportunities for supporting the areas of social engagement and nonverbal communication in which they have some of their most profound difficulties (153).

Thus, teaching the skills necessary to comprehend emotion processing has a significant life-long impact for persons with ASD, highlighting the critical need for evidence-based interventions to assist these individuals in improving their social and emotion recognition skills. Further research in the area of emotional music

perception and music-based therapies may provide some clues about effective intervention strategies for the treatment of socio-emotional deficits in ASD.

CONCLUSION

In conclusion, research suggests that individuals with ASD have marked difficulties with emotional communication and social interactions – evidenced early in development by lack of emotional engagement and atypical patterns of inter-subjective behavior. However, individuals with ASD do not appear to have difficulties recognizing simple emotions in music, in fact, they show an affinity for music, and may have some superior abilities with specific aspects of music processing. These findings imply a possible avenue for the development of more effective music-based therapeutic interventions to improve socio-emotional functioning in ASD. The human MNS, by creating a link at the neural level between two interacting agents (e.g. the therapist and the patient), offers a neural substrate for music's therapeutic potential. However, empirical studies – both neural and behavioral - are still required to further clarify the possible beneficial role of music for individuals with ASD. In particular, behavioral studies that investigate the role of music in ameliorating social deficits, such as using musical cues to teach the meaning of other socially salient information, to individuals with ASD will be crucial. Neuroimaging studies will also be essential to help us understand how brain systems, such as the MNS, which reportedly underlie social deficits in ASD, can be activated by music to support social understanding. Such future research has the potential to provide a 'doorway' to evidence-based therapeutic interventions of great benefit to this population.

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