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Music: a unique window into the world of autism

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Understanding emotions is fundamental to our ability to navigate the complex world of human social interaction. Individuals with autism spectrum disorders (ASD) experience difficulties with the communication and understanding of emotions within the social domain. Their ability to interpret other people's nonverbal, facial, and bodily expressions of emotion is strongly curtailed. However, there is evidence to suggest that many individuals with ASD show a strong and early preference for music and are able to understand simple and complex musical emotions in childhood and adulthood. The dissociation between emotion recognition abilities in musical and social domains in individuals with ASD provides us with the opportunity to consider the nature of emotion processing difficulties characterizing this disorder. There has recently been a surge of interest in musical abilities in individuals with ASD, and this has motivated new behavioral and neuroimaging studies. Here, we review this new work. We conclude by providing some questions for future directions.

Keywords: ASD; alexithymia; insula; mirror neurons; emotion

The ability to enjoy music is a universal human trait and we engage with it spontaneously and effortlessly. Music is unique in the extent that it triggers memories, awakens emotions, and intensifies our social experiences. Through music we are exposed to the thoughts, emotions, and ideas of others, and the experience of music listening enables us to learn how to combine elements of sound in a coherent communicative stream that may be as important as learning how to "talk scientifically" in science lessons.[1] Music allows us to develop self-knowledge, self-identity, and group identity, enabling us to share thoughts, emotions, and feelings, and understand those subtle and unique human experiences that cannot easily be put into words.[2]

Although music psychologists have long emphasized the intensely social nature of musical activities, considerably less thought has been given to the intrapersonal consequences of musical engagement. Unfortunately, social isolation is not uncommon, and for individuals with psychiatric or psychological disorders, this may be a constant experience. In these cases, music may become increasingly important as a means of alleviating loneliness and suffering, as well as improving communicative and cognitive abilities.[3]

Autism spectrum disorder (ASD) is an umbrella term used to describe a continuum of diagnoses that include autism, 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.[4] Theoretical accounts of the social and communicative difficulties in ASD have tended to differ in the degree of importance allocated to cognitive or affective factors. The theory of mind (ToM) account of autism, first described by Baron-Cohen *et al.*,[5] proposes that ASD is characterized by a fundamental difficulty with representing the mental states of others. In contrast, Hobson has stressed the importance of intersubjectivity, and the developmental sequelae of an early disturbance in the ability to form emotional bonds with others.[6] To help explain the

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wide range of impairments in ASD, Dawson *et al.* have proposed the social motivation hypothesis, which holds that the social impairments in ASD are only secondary to a primary deficit in social motivation.[7,8] More recently Ramachandran and Oberman have proposed a "broken mirrors" hypothesis of autism.[9] According to this account, the ability to understand the intentions and actions of others depends upon an intact mirror neuron system (MNS), which is compromised in ASD.[10,11]

Improvements in the early identification of autism have enabled researchers to study social and communicative behaviors in infants and young children at risk for autism and to look for early precursors of later emerging social and communication abnormalities. These studies have revealed a number of interesting findings. Numerous studies have reported imitation deficits in autism.[10,12,13] Rogers and Pennington suggested that motor imitation may be one of the primary deficits, and they highlighted two subcomponents of imitation that might underlie the imitative deficit in autism—self–other correspondence and the sequencing of intentional movements.[12] In support of this theory, Vanvuchelen *et al.* found that individuals with autism showed impaired performance in both gestural imitation and general motor skills, suggesting that their imitation deficits may be part of a broader perceptual–motor problem.[14] Furthermore, Perra *et al.* found that children with autism performed worse than typically developing children and children with general developmental delay on imitation and ToM tasks.[15] Deficits in imitation can have extensive ripple effects, as imitation scaffolds the development of language, cultural transmission, and social communication.

Studies have also shown that the characteristic interest in faces shown by typically developing infants is significantly reduced in infants and children with autism.[16–19] Social referencing, a tendency to look to significant others in ambiguous situations, is also atypical in children diagnosed with autism. Whereas typically developing infants use social referencing to make sense of confusing or threatening situations,[20] children with autism are less likely to reference another person in these same instances.[21] Young children with autism are also unlikely to voluntarily share their experience with others, and often avoid initiating interactions with multiple social partners, even when guided to do so.[22] Studies that have specifically focused on the role of emotion processing deficits in social understanding and reciprocity have shown that individuals with ASD display less positive emotion to their social partners[23,24] when compared to typically developing peers and experience more negative affective exchanges with others.[25] Reduced attention to other people's emotional cues may result in negative peer interactions and increased difficulties in resolving conflict with others. Although some experimental studies directly testing emotion recognition have failed to observe deficits,[26–29] the findings from the majority of studies are consistent with clinical reports of poor emotion understanding.

An important recent avenue of research into emotion processing deficits has investigated the co-occurrence of ASD and alexithymia. Alexithymia is a disorder characterized by reduced or absent affective responses (type I alexithymia) or difficulties in understanding and ascribing affective labels to one's own physiological states of arousal, even when affective arousal is present (type II alexithymia).[30] Whereas compromised emotional awareness, or type II alexithymia, is estimated to affect around 10% of the general population,[30] a much higher prevalence rate of 85% has been observed in a sample of intellectually high-functioning adults with ASD.[31–34]

Using functional neuroimaging, Silani *et al.* showed that high levels of alexithymia, measured using the Toronto Alexithymia Scale,[35] were associated with hypoactivation in the anterior insula in individuals with high-functioning autism.[36] Furthermore, there was a significant correlation between activity in the insular cortex not only with alexithymia scores, but also with scores on empathic concern and perspective-taking scales. In a more recent study, the same authors measured empathic brain responses in participants with ASD and neurotypical controls while they witnessed another person experiencing pain.[37] The results were consistent with those of the original study, showing that the levels of alexithymia, but not a diagnosis of autism, were associated with the degree of empathic brain activation in anterior insula. These results are important in showing that the empathy deficit widely attributed to ASD can be explained by the extent of alexithymic traits and does not constitute a universal social impairment in autism.

One interesting question that arises from this recent work is how alexithymia would affect musical

appreciation. Behavioral studies that have compared children with autism and age- and intelligence-matched typical controls on their ability to match musical extracts with visual representations of different emotions have failed to reveal group differences.[38,39] This work suggests that difficulties in recognizing emotions in social stimuli (voices and faces) do not generalize to the domain of music. In a study that specifically investigated the impact of alexithymic traits on music perception, Allen *et al.* asked groups of intellectually able adults, with and without ASD, to select words that described their personal responses to music. Although the high-functioning adults with autism did select fewer emotion words than controls, the data showed that the severity of the participants' alexithymic traits, rather than their diagnostic status, explained this result. In the study, galvanic skin response measures were taken while the participants listened to musical excerpts. The analyses of these data failed to observe a between-group difference in autonomic responses to music, showing that a physiological-level response is also preserved in the population with ASD.[40]

This work, providing evidence for unimpaired appreciation of music's affective qualities in ASD, raises interesting questions about how such understanding is acquired and what the consequences of it may be. Many infants and children with ASD fail to attend to faces and voices (e.g., Ref. 19), and this reduces their opportunities to learn about other people's emotions. Studies have shown that mothers mimic their infant's facial expressions of emotion, and infants who are underresponsive to such maternal feedback may fail to associate their own bodily states of arousal with the emotion categories mirrored by their mothers.[41,42] Atypical attention at early stages of development may therefore impoverish both inter- and intrapersonal emotional understanding. But what about music? In Kanner's first case account of autism he described an unusual preoccupation with music that co-occurred alongside the social and communicative disabilities that are still core criteria for autism.[43]

In a recent observational pilot study, we tested patterns of attention in response to musical and other auditory stimuli in 20 autistic and typically developing children engaged in play activity at school. The stimuli were either short sentences (e.g., "those look like nice toys"), environmental noises (door opening and closing), or short excerpts of classical music. The children's responses to the sounds were recorded using a video camera and coded for positive affect, vocalization, orientation–coordination, and anticipation–increased focus. The results showed that the children with autism were more responsive to all stimuli than the typical children and this may reflect sensory and/or attentional difficulties. However, there was also a significant between-group difference in the pattern of performance across the three different conditions. Whereas the typical children showed a similar pattern of response to music, speech, and environmental noise, the children with ASD showed a statistically significant increase in their responses to music compared with speech and environmental noise. These results strongly suggest that music elicits special attention for children with autism and may help explain the feats of musical memory initially described by Kanner.[43]

These findings also increase our understanding of how children with ASD come to understand musical emotions when emotions expressed on faces and in voices are so difficult to interpret. It appears that music is spared the characteristic early "neglect" accorded to social stimuli. Given the potential therapeutic implications of this, questions about the nature of spared musical emotion recognition are important. To address the question of whether children with ASD, who recognize emotions in music, will recognize those same emotions in verbal information, we carried out an experimental study of domain-general auditory emotion recognition. In the study, 15 intellectually able children with autism and age- and intelligence-matched typical controls were asked to identify happy, sad, and fearful emotions in short musical excerpts, nonverbal vocalizations (affective vocal gestures), and vocalized three-digit numbers (e.g., 523) spoken with affective intonation. Consistent with other recent studies (e.g., Refs. 28 and 29), the results failed to reveal emotion recognition deficits in the ASD group. However, an interesting finding was revealed by the correlations carried out on the data from the different experimental conditions. For typical children, good categorization of nonverbal emotional vocalizations was strongly associated with good categorization of music. It appeared that for them, affective cues in music and vocal gesture were similarly accessible but that this was not the case for verbal

information. For the children with ASD, all correlations were significant, so the ability to extract expressive cues from music and vocal gesture also generalized to speech. This finding could have implications for therapies aimed at remediating impoverished perception of affective prosody in ASD.

Although most influential theoretical accounts of ASD focus on explaining specific aspects of the disorder (e.g., ToM[5]), others have been more ambitious in scope. For example, the broken mirrors hypothesis has attempted to account for wide ranging difficulties in joint attention, social orienting, imitation, emotional responsiveness, and face processing under the umbrella of a compromised MNS.[9] The MNS functions as a sort of "neural Wi-Fi," which allows an observer to understand the actions of another by activating the same regions of their brain as if they were performing the actions themselves through a process called simulation (for reviews, see Refs. 44 and 45). As a result, the MNS has been conceptualized as a neural hub that plays a seminal role in action perception, imitation, language, intention understanding, perspective taking, and self–other discrimination.

Based on the simulation mechanism implemented by the human MNS, Molnar-Szakacs and Overy have developed the Shared Affective Motion Experience (SAME) model of emotional music perception.[3,46,47] The SAME model suggests that musical sound is perceived not only in terms of the auditory signal, but also in terms of the intentional, hierarchically organized sequences of expressive motor acts behind the signal. Expression *and* perception of these "musical motor acts" (clapping, singing, and plucking strings) lead to recruitment of the same neural systems in the musician making music and the listener perceiving it—allowing for a shared affective motion experience.

At the neural level, SAME relies on a network whose key nodes are the human MNS, the anterior insula, and the limbic system. The auditory features of the musical signal are processed primarily in the superior temporal gyrus (STG) and are combined with structural features of the expressive motion information within the MNS. The anterior insula forms a "communicative channel" between the MNS and the limbic system, allowing incoming information to be evaluated in relation to the perceiver's autonomic and emotional state. This then combines with top–down cognitive information and can lead to a complex affective or emotional response to the music.[3,46,47]

A recent study was designed to test the neural model proposed by SAME.[48] High-functioning children with ASD and age-matched controls listened to happy, sad, and peaceful music[49] and made button-press responses to indicate whether they thought the musical excerpt sounded happy, sad, or peaceful while their brain activity was recorded using functional magnetic resonance imaging (fMRI). In both groups of children, preliminary results revealed a strong activation in the STG bilaterally and within a network, including right posterior inferior frontal gyrus (IFG) and premotor cortex—areas composing part of the human MNS—while they listened to emotional music compared to rest. The thalamus—known to play an important role in preprocessing auditory signals and projecting the information into the auditory cortex—was also recruited. Activations were also seen in the amygdala, medial orbitofrontal cortex, and anterior cingulate cortex—structures implicated in the processing and regulation of emotion.[50,51]

Behavioral data collected during the study showed that children with ASD identified the emotional musical excerpts as well as the neurotypical control participants. Consistent with results from other studies (e.g., Ref. 49), both groups were significantly faster at identifying happy music than sad or peaceful music.

Although these results are preliminary, they correspond well to similar studies in neurotypical individuals, which have found that affective responses to music recruit a network of paralimbic regions (cingulate cortex) and temporal lobe regions (superior temporal sulcus/superior temporal gyrus),[52–54] and also the posterior inferior frontal gyrus and premotor cortices.[53,54] These data provide support for the SAME model of affective musical experience, whereby recruitment of the MNS allows children with ASD to experience and understand emotional music.[48] Furthermore, these results challenge the idea that mirror regions in the autistic brain are "broken," as has previously been proposed.[9,10]

In another recent fMRI study, Caria *et al.* investigated emotion processing in individuals with ASD during the processing of happy and sad music excerpts.[55] Overall, fMRI results indicated that while listening to both happy and sad music, individuals with ASD activated cortical

and subcortical brain regions known to be involved in emotion processing and reward. Interestingly, a comparison of participants with ASD and neurotypical individuals demonstrated decreased brain activity in the premotor area and in the left anterior insula, especially in response to happy music excerpts. The authors conclude that individuals with ASD are able to perceive simple emotions in the musical domain, and impairments of emotion processing in ASD appear to be stimulus specific (i.e., faces[56–58]).

In a recent comprehensive meta-analysis of functional neuroimaging studies of social processing in ASD, Di Martino *et al.* demonstrated that across a group of 24 studies examining various aspects of social processing ranging from face processing to ToM, one of the regions consistently showing significant hypoactivity in ASD was the right anterior insula.[59] The right anterior insula has been associated with subjective perception of emotional states[60,61] and awareness of emotionally salient stimuli.[62,63] It has been posited that the anterior insula, along with the anterior cingulate cortex, serve as a key substrate for the conscious experience of emotion and for the central representation of autonomic arousal, as they integrate visceral, attentional, and emotional information.[64,65] Evidence from brain network analyses suggests that the anterior insula can be considered as part of a ''salience network,'' which serves to integrate sensory data with visceral, autonomic, and hedonic information,[66] making it a region that is critically involved in social–emotional processing.

In the study by Caria *et al.*, hypoactivation of the left anterior insula in response to music in the ASD group compared with the neurotypical group provides further confirmation of the importance of this region as the site of differences in sensitivity to emotion-inducing stimuli in autism.[55] These results are echoed in the neuroimaging studies on alexithymia.[36,37] Both of these studies showed that high levels of alexithymia were associated with hypoactivation in the anterior insula in individuals with high-functioning autism. Furthermore, several studies investigating the perception of faces[59,67] and eye gaze[68] were also associated with hypoactivity of the anterior insula in ASD. These data show that the role of this neural region in emotion perception and understanding is not specific to music, but is rather domain general. Considerable evidence exists about the crucial role of the anterior insular cortex in the representation of internal bodily states of arousal as well as emotional awareness or second-order (interoceptive) awareness.

Taken together, these data suggest that the anterior insula plays a seminal role in the emotion–perception related deficits seen in autism. As discussed earlier, the SAME model assigns a central role to the anterior insula in emotional music perception as a communication hub and center of integration of information coming from the MNS and the limbic system. Future neuroimaging work should address the functional and structural connectivity of the anterior insula. In a complex disorder such as ASD, it is likely that disruptions in interactions within and between large-scale brain networks, rather than focal deficits, underlie the symptoms.[66] Critically, the anterior insula serves a fundamental function with respect to representing and evaluating salient stimuli, and is uniquely positioned as a hub, mediating interactions between large-scale brain networks involved in attentional and self-directed processes.

Based on this review of recent behavioral and neuroimaging work in autism, we conclude that impaired emotion recognition, characteristically observed within socioemotional and interpersonal domains, does not generalize to music. Results showing that musical understanding and appreciation is intact in individuals with ASD may help to explain the efficacy of music therapies carried out with this group.[3] Music, as a form of nonverbal communication, constitutes a domain of preserved skills and interest and is a powerful and accessible affective stimulus that captures and emotionally rewards individuals with ASD.

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Conflicts of interest

The authors declare no conflicts of interest.

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