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Exploring Neural System Abnormalities in Autism Spectrum Disorders: A Comprehensive Review

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ABSTRACT

Autism spectrum disorder (ASD) is one of the most severe developmental disorders, usually diagnosed before the age of 3 years. While the symptoms and severity can vary from person to person, all forms of autism impair an individual's ability to communicate effectively. Although there is no known cure for autism, early and intensive intervention significantly improves the quality of life for affected children. Research in social neuroscience suggests that deficits in social functioning observed in individuals with autism may be due to abnormalities in the neural systems responsible for processing social information. This study reviews the available evidence on the neurological foundations of ASD and highlights abnormal activity in areas of the mirror neuron system and its interconnected regions, including regions involved in social perception, action observation, and theory of mind. The findings suggest that ASD is characterized by dysfunction of neural circuits involved in social processing, affecting the ability to perceive social cues, understand actions, and develop a theory of mind. Furthermore, the posterior superior temporal sulcus emerges as a key region involved in all three systems, providing insights into the brain mechanisms underlying the social deficits seen in ASD.

Keywords: Social neuroscience, Autism spectrum disorders, Neural systems, Developmental disorders

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Introduction

Autism spectrum disorder (ASD) is a condition characterized by delays or abnormalities in social interaction, communication, and symbolic or imaginative play. Children with ASD tend to immerse themselves in their world, and since effective social interaction requires accurate sensory processing and the ability to respond appropriately, their disconnect from the outside world leads to difficulties in learning and social engagement [1, 2]. The field of cognitive neuroscience has increasingly focused on the neural mechanisms that underlie social information processing and the social brain in humans. The rapidly growing field of social neuroscience has contributed significantly to understanding both normal and atypical social cognition [3, 4]. Given the complexity of these mechanisms, it is crucial to explore how autism spectrum disorders affect the neural systems involved in social perception and processing.

This study reviews the available evidence on the neurological foundations of ASD and highlights abnormal activity in areas of the mirror neuron system and its interconnected regions, including regions involved in social perception, action observation, and theory of mind.

Results And Discussion

Neural Mechanisms of Social Perception

Humans are inherently social, and social perception—the ability to interpret others' mental states through behavioral cues—plays a vital role in social functioning. This skill is evolutionarily advantageous as it helps individuals navigate social environments [3, 5, 6]. Primates serve as an important model for studying social perception in humans, as many of their social behaviors mirror those seen in human interaction [7, 8]. For example, chimpanzees can infer what others know during competitive situations and use that understanding to assist others [9, 10]. Studies of Rhesus monkeys show their ability to interpret others' thoughts through auditory and visual cues [11, 12].

Several brain areas work together to support social perception, including the fusiform gyrus (FFG), amygdala (AMY), orbitofrontal cortex (OFC), and posterior superior temporal sulcus (PSTS). These regions are involved in processing social stimuli and are interconnected in both humans and primates [13, 14].

PSTS is a key component of the social perception network. This region is linked to primary visual and auditory centers and plays a role in processing social information from both domains [15, 16]. PSTS responds to both static stimuli, such as faces, and dynamic stimuli, like changes in gaze direction or facial emotions [16, 17]. It is particularly activated when stimuli are perceived as intentional, highlighting its role in understanding purposeful social behavior [16]. In the auditory domain, PSTS also plays an important role in processing emotional speech.

The FFG includes several interconnected regions in the ventral-temporal cortex, such as the fusiform face area (FFA), which is sensitive to facial cues, and the fusiform body area (FBA), which responds to body-related stimuli. The FFA is involved in the recognition of faces and the processing of implicit face-related information, such as eye movements [18]. Additionally, FFA contributes to facial identity recognition and goal-directed behavior [19].

The AMY is crucial for encoding the emotional significance of social information, especially in rapid processing situations [20]. It helps orient attention to socially important features, such as eyes, particularly when facial expressions indicate emotions like fear [21]. The OFC is integral to processing the value of sensory stimuli, playing a role in decision-making and behavioral planning [22]. This region helps individuals focus on rewarding social cues and engage appropriately in social interactions [23].

Research on the social development and challenges faced by individuals with autism spectrum disorders (ASD) has enhanced our understanding of their social perception difficulties. Unlike typical children, those with ASD are less responsive to social cues such as voices and faces [24]. At a young age, children with ASD often focus more on non-social and physical aspects of their environment, missing the social significance of biological functions that their peers recognize [25].

The social difficulties that children with autism experience tend to persist into adulthood. Adults with ASD, especially those with high-functioning autism, struggle with understanding the mental states of others, interpreting vocalizations, and recognizing emotional expressions on faces [26]. These findings provide strong evidence of abnormal social perception processing in both cortical and subcortical regions, including somatosensory, auditory, and visual pathways. Studies in visual processing show that key brain regions, including the AMY, FFC, and PSTS—critical for social perception—are less active in children with autism when compared to their neurotypical siblings [27]. Furthermore, individuals with autism show reduced selective activity in the PSTS when processing social information. For instance, in contrast to typical individuals, those with ASD are less able to distinguish inconsistencies in actions and displayed preferences during a show. In the auditory domain, while they display similar activity patterns to controls in response to non-vocal sounds, the regions of the PSTS responsible for vocal sound processing become inactive. In terms of somatosensory signals, individuals with higher autism traits show reduced activation of the OFC and PSTS when exposed to light touches [28, 29].

The Action Observation Neural System

While social perception involves understanding others' outward behaviors to infer their intentions, perceiving action requires more involvement from the observer. When watching others' actions, the perceiver must consider what those actions might imply if they were to perform them themselves. This process highlights the importance of self-perception in action comprehension, emphasizing that observing others' actions is inherently tied to self-awareness. This mechanism is encapsulated in the "action observation" neural system. To effectively understand the actions of others, perceivers must not only decode external behaviors but also mentally simulate these actions [30].

The concept of mirror neurons, which are a type of visuomotor neuron identified first in monkeys' prefrontal cortex, plays a crucial role in understanding the neurological basis of action observation. These neurons have been found in both humans and monkeys in response to both action observation and execution. The mirror neuron system in humans involves three key brain regions [31, 32]: the parietal mirror neuron area, located in the inferior parietal lobule (IPL), which offers a basic motor description of others' movements; the PSTS, which processes the visual dynamics of these actions; and the frontal mirror neuron region, encompassing the ventral premotor cortex (PMC) and the posterior inferior frontal gyrus (IFG), which generates high-level motor plans. This coordinated process of action perception forms the core mechanism of the mirror neuron system.

The IPL (inferior parietal lobule) and IFG (inferior frontal gyrus) receive processed data from the PSTS (posterior superior temporal sulcus), which then sends this information back to both the IPL and PSTS. This interaction means that the PSTS functions as both an input and output area in the mirror neuron system, allowing for comparison between observed actions and performed actions. Research on action observation is growing, though it is still in its early stages. While some studies have shown that children with autism struggle with imitation tasks or experience delayed development compared to their typically developing peers, it remains unclear whether imitation difficulties are a core issue in autism [33]. Other research, however, has reported no significant differences in imitation abilities between children with autism and those in the control group [34, 35].

The mirror neuron system's role in autism has been examined through various neuroimaging techniques, with mixed findings. For example, functional MRI studies suggest that children with autism show atypical activity in regions such as the TFG (temporal fusiform gyrus) and IPL when observing facial expressions or hand gestures [36]. Additionally, electroencephalography (EEG) results typically show a suppression of the mu rhythm in typically developing individuals during the observation and execution of hand movements, but this suppression is absent in those with autism spectrum disorders. However, other studies found no significant differences in the neural activity of brain regions related to the mirror neuron system between individuals with autism and the control group [37, 38]. Interestingly, research showing abnormal mirror neuron system activity often uses emotional stimuli, while studies showing typical activity tend to use non-emotional stimuli [39]. This area of research is evolving, and work is ongoing to clarify the distinct roles of various regions within the mirror neuron system.

Theory of Mind and Neural System Malfunction

In recent decades, research on the theory of mind—also known as mentalizing or reasoning about mental states—has contributed significantly to our understanding of both typical and atypical social behavior. Theory of mind refers to the ability to understand and predict the relationship between internal mental states and external circumstances. To do so, individuals must be able to distinguish their perspective from that of others [40]. This ability, believed to be unique to humans, requires considerable cognitive resources and high levels of attention. Mastering the theory of mind is critical for navigating complex social environments by comprehending and predicting others' mental states [41].

The famous Sally-Anne experiment, conducted by Wimmer and Perner in 1983, was designed to test a theory of mind in young children [42]. In this experiment, children watch two dolls, Sally and Anne. After placing a stone in her basket, Sally leaves the room. While she's away, Anne moves the stone from Sally's basket into her box. The children are then asked where Sally will look for the stone when she returns. If the children understand Sally's perspective—i.e., that Sally mistakenly believes the stone is still in the basket—they will correctly answer that Sally will look in the basket. This ability to understand another person's false belief is a developmental milestone, typically acquired by children around age four. By the age of six or seven, most children can complete second-order false belief tasks [43].

Research indicates that the ability to reason about mental states, including moral judgments, develops further from puberty into adulthood. People with autism spectrum disorders (ASD) show clear impairments in theory of mind, which is the ability to attribute mental states to oneself and others. For instance, in the Sally-Anne task, children with ASD, despite being older by about five years compared to their peers, failed to recognize Sally's mistaken belief [44]. Various studies comparing the ability to reason about beliefs in typical and atypical children suggest that this inability is indicative of more profound social challenges in ASD [45, 46]. Although children with ASD who have moderate to high IQs are capable of solving simpler false-belief tasks as they mature, they still face difficulties in more complex scenarios involving social emotions and intuitions. These challenges persist into adulthood. For example, while adults with high-functioning autism can comprehend false beliefs during tests, they struggle to predict them spontaneously based on others' behavior [47].

Extensive research on the theory of mind has provided valuable insights into how people with ASD and typical individuals make inferences about mental states. Numerous neuroimaging studies have explored these deficits, with many finding that individuals with ASD show lower activation in key areas like the medial prefrontal cortex

(MPFC) and temporal-parietal junction (TPJ) compared to those without the disorder. The more pronounced the symptoms of ASD, the greater the decrease in activity in these regions [48]. However, other studies have shown no significant differences in neural activity during theory of mind tasks that involve narratives when comparing ASD subjects to control groups [49-52].

In summary, findings from recent research suggest that individuals with ASD exhibit atypical patterns of brain activity, with reduced activation in critical areas like the TPJ and MPFC when trying to understand the mental states of others.

Conclusion

Research has identified several brain regions that play a role in social perception, including the posterior superior temporal sulcus (PSTS), amygdala (AMY), orbitofrontal cortex (OFC), and fusiform gyrus. Studies investigating the neural mechanisms of social information processing in individuals with autism spectrum disorders (ASD) show that these areas are also implicated in the disorder. These individuals display reduced activity in regions responsible for action observation, such as the mirror neuron system, and its interconnected areas like the posterior cingulate cortex, inferior frontal gyrus, and inferior parietal lobule. Additionally, deficits are observed in areas involved in theory of mind, including the middle prefrontal cortex, temporal-parietal junction, and PSTS.

Among these, PSTS stands out as a critical hub that integrates information from different sensory inputs, including vision, sound, and touch, to form an understanding of others' actions and intentions. This integration, known as temporal integration, is essential for predicting and understanding future behaviors based on past events. In ASD, improper functioning of PSTS can make it difficult for individuals to predict others' actions, which supports the theory of impaired temporal prediction in ASD. According to the predictive impairment in autism (PIA) hypothesis, individuals with ASD struggle with estimating the likelihood of sequences of events, leading to challenges in adapting to dynamic environments. This hypothesis provides insight into various traits of ASD, such as sensory sensitivity, repetitive behavior, difficulty with social interactions, and strengths in structured, rule-based tasks like mathematics or music.

Moving forward, it would be valuable for research to further explore the role of PSTS in temporal integration, particularly concerning the PIA hypothesis, to better understand its contribution to the characteristics of autism spectrum disorders.

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