

The Neurological Characteristics of Autism Spectrum Disorder

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Abstract. Autism Spectrum Disorder (ASD) is a multifaceted neurodevelopmental condition that predominantly affects males and manifests through diverse behavioral impairments, such as difficulties in social engagement and a tendency towards limited, recurrent behaviors. Concepts like the theory of mind and the executive function theory notably emphasize the underlying aspects of the condition, highlighting deficits in understanding others' mental states and domain-general cognitive difficulties, respectively, though receiving varying levels of empirical support. A focus on neurological perspectives, utilizing tools like functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG), is indispensable for unveiling intricate patterns and alterations in brain regions crucial for social cognition and empathy, such as the superior temporal sulcus (STS) and amygdala (AMY). These neurological insights are pivotal in painting a holistic picture of ASD, emphasizing not just the behavioral manifestations but also the underlying neurological substrates. Such an integrated approach is crucial for advancing the current understanding, refining diagnostic methodologies, and developing more targeted interventions, which are vital for addressing the diverse needs and challenges faced by individuals with ASD.

Keywords: neurological mechanism; autism spectrum disorder; social communication deficit.

1. Introduction

Autism Spectrum Disorder (ASD) is a certain type of developmental neurological disorder that widely distributed among all groups of people, especially with higher prevalence in males than that of female. The research on the developmental stage is of indubitable importance because better understanding towards the neurological profile of children at an early stage could be conducive to inventions of more effective intervention and more accurate ways of ASD diagnosis in the future. Apart from that, since most children who have been diagnosed with ASD have passed their most sensitive time. And they have already formed into sensory difficulties. The emphasis should be on identifying potential neurological markers for ASD to facilitate early diagnosis of its symptoms. This would enable more prompt interventions and might possibly prevent the onset of ASD at its initial stage. Moreover, as neurological research and research in brain science are closely related, research on ASD at the aspect of neurological characteristics could contribute to the understanding of brain development and make a better comparison between the social ability in the children with ASD and that in the typical children.

Individuals with ASD can have symptoms that range from mild to severe and the presentation of ASD can vary widely from person to person. According to the findings of Rice et al., those diagnosed with ASD have several behavioral deficits [1]. The first one is social challenge including difficulties with social interactions and impaired communication. The second one is restricted and repetitive behaviors (RRBs), especially with a strong inclination to engage themselves in rituals and a resistance to change. And the third one is an intense focus of fascination with specific topics or objects. There are two major theories proposed by Jones et al. that underly the cause of ASD [2]. The most famous one is the theory of mind theory deficit in ASD. It argues that ASD is associated with deficits in understanding others' mental states and predicting behavior, impacting social communication. Individuals with ASD often struggle with false belief tasks, reflecting theory of mind deficits, although some can pass such tasks with sufficient verbal ability. However, this ability may not translate to real-life situations where intuitive and fast mentalizing is required. And the theory of mind

theory does not fully explain RRBs in ASD and has mixed empirical support regarding its association with social communicative behaviors.

Another theory is the executive function (EF) theory, it posits that individuals with ASD experience domain-general cognitive difficulties that significantly impact complex, novel, and goal-oriented behaviors. These cognitive abilities, overseen by the frontal lobes, encompass strategizing, restraint, mental adaptability, idea creation, and short-term memory recall. Deficiencies in executive functions are theorized to limit the capacity of individuals with ASD to introspect and understand others' mental states, influencing social interaction and theory of mind development. Inadequate executive functions are also associated with restricted, repetitive behavior. For example, challenges in conceptualizing novel ideas can result in inflexible routines and difficulties adapting to alterations in established patterns. However, the correlation between EF deficits and behavioral symptoms in ASD is not consistently supported by empirical studies, as many findings are varied and contradictory, showing no significant associations between symptom severity and specific cognitive domains.

In diagnosing ASD, functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG) serve as principal neurological approaches, each offering distinct insights into brain function. fMRI delves into the nuances of the brain's functionality and structural elements related to social interaction and cognition, exposing hypo-activation in regions like the superior temporal sulcus (STS), middle temporal gyrus (MTG), and amygdala (AMY) in individuals with ASD [3]. These areas, integral for emotional face perception and empathetic reactions, exhibit irregularities reflective of compromised emotional response and empathy in ASD patients compared to controls. The importance of the STS and AMY lies in their crucial role in recognizing and correlating emotions, hence influencing empathetic responses. Concurrently, EEG, a non-invasive diagnostic method, captures the intricate electrical patterns within the brain, utilizing electrodes on the scalp to detect neuronal impulses, proving essential in monitoring diverse neurological disorders affecting brain activity, such as epilepsy and sleep disorders. The inferior frontal gyrus (IFG) is associated with the mirror neuron system and is crucial for mirroring others' emotions, while regions like the medial prefrontal cortex (MPFC), posterior superior temporal sulcus (pSTS), and temporoparietal junction (TPJ) are central to understanding and interpreting others' mental states and intentions. The synthesis of findings from both fMRI and EEG uncovers the complex neurological substrates and deviations in ASD, enriching researchers' comprehension of the disorder by detailing the multifarious abnormalities influencing social cognition, emotional perception, and empathetic interactions, thereby aiding in narrowing the existing gaps in ASD research and diagnosis.

Apart from that, current identifications of ASD are mainly composed of intrinsic identification and extrinsic identification. Intrinsic identification centers on the internal techniques or the evaluative elements employed in recording trends in ASD prevalence. This concept pertains to the discrepancies in research approaches, potentially leading to variations in the categorization of individuals as having or not having ASD. And the extrinsic identification refers to the external factors that influence the identification of people with ASD, such as modifications in diagnostic standards or availability of services contingent on an ASD designation [4]. Access to services may also influence who gets diagnosed as people with access to healthcare and educational resources may be more likely to receive an ASD diagnosis. Etiological changes or true alterations in ASD manifestations within the populace, associated with individual or amalgamated genetic, biological, or environmental factors. It deals with understanding specific vulnerabilities or exposures that make an increment in the likelihood of developing ASD. Understanding these risks is crucial in forming a comprehensive view of ASD.

The theory of mind theory highlights deficits in ASD individuals in understanding others' mental states, impacting social communication but has mixed support and doesn't fully explain ASD related RRBs. The EF theory emphasizes domain-general cognitive difficulties impacting various complex behaviors and contributing to RRBs in ASD. However, empirical studies yield inconsistent findings regarding the correlation between EF deficits and behavioral symptoms in ASD, making definitive conclusions challenging. It has come clear that there is a reservoir of research on ASD at the behavioral profile. However, little is known about the ASD at the neurological profile. Therefore, the

convergence of insights from fMRI and EEG, highlighting the structural and functional peculiarities in regions like the STS, AMY, IFG, MPFC, pSTS, and TPJ, provides a more nuanced understanding of ASD. This combination allows for a multifaceted exploration, unveiling the intricate neurological underpinnings and abnormalities associated with ASD that impact social interaction, empathy, and emotional perception. The amalgamation of discoveries from these two neurological approaches in recent years is crucial to bridging existing knowledge gaps in ASD diagnosis and understanding.

2. Atypical Neural Connectivity in ASD

In this study by Carson et al., children with high-functioning ASD and the typically developing children (TDC) underwent EEG data collection while viewing video stimuli, ensuring adherence to the Declaration of Helsinki and attaining approvals from Internal Review Boards [5]. The children were aged around 10 years, with no notable variance in age or intelligence quotient among the groups. The kids watched two narratives, each five minutes long, randomly presented and conveyed by a recognizable individual (their guardian) and an unknown person, with EEG being recorded for each condition. The brain regions such as frontal cortex, temporal lobes, corpus callosum (CC), parietal lobes and occipital regions were tested as they played a pivotal role in the emotional processing. The EEG data was meticulously analyzed, revealing significant main effects of group, frequency band, and electrode pair. Furthermore, several noteworthy interactions and main effects across different frequency bands were observed, particularly in the alpha frequency band, focusing the subsequent analyses on this band. It showed a prominent group effect between the ASD and typically developing groups within specific electrode pairs, indicating distinct coherence in baseline conditions. The typically developing group exhibited a more considerable baseline z-transformed synchrony compared to alternative circumstances, whereas the ASD group did not show significant differences between conditions. Nonetheless, no notable variations were noted across the groups as for conditions of familiar and unfamiliar videos, and no substantial main effects or interactions were discovered in certain electrode pairs. The findings contribute valuable insights into neural coherence differences in children with and without ASD under varied conditions, emphasizing the role of the alpha band and suggesting differing neural responses between the two groups.

In the research conducted by Alaerts et al., the sex-related variances of those with ASD in functional connectivity were explored through resting-state fMRI [6]. And it was evident that the factor plays a pivotal role in ASD, demonstrating varied connectivity patterns between the two genders. Males with ASD predominantly exhibited hypo-connectivity, particularly highlighting diminished connectivity in regions like the fusiform gyrus and thalamus—areas pivotal for social cognition and emotion processing. This diminished linkage in males with ASD was seen in comparison to the typical control males, delineating a distinct pattern associated with the disorder. When contrasted with typical control (TC) females, females with ASD exhibited a pattern of heightened connectivity, revealing increased connectivity predominantly in frontal regions associated with higher-order cognitive functions. The highlighted increased connectivity in ASD females in comparison with TC females presents a clear differential pattern in functional connectivity between the genders within the ASD context. Alaerts and his colleagues also performed investigative whole-brain ROI-to-ROI functional linkage assessments on ASD-diagnosed and TC participants, utilizing a comprehensive brain segmentation consisting of 200 ROIs. The findings indicate divergent connectivity patterns; males with ASD displayed reduced connectivity, whereas females displayed hyper-connectivity compared to their TC counterparts. These distinctions in connectivity underscore potential gender-based differential presentations in ASD, emphasizing the necessity of gender-inclusive research approaches in studying ASD.

3. Impaired Socio-Emotional Neural Activity in Children with ASD

In a research study conducted by Kim et al., neurological responses to emotional stimuli in ASD children and TDC have been examined through detailed fMRI scans [7]. A refined selection process

ensured 17 children with ASD and 24 TDC participated, all with comparable age and intelligence, after eliminating those with specific medical conditions. And it involved meticulous assessments, using several standardized tools, including the Autism Spectrum Screening Questionnaire and the Autism Diagnosis Interview-Revised-Korean version, ensuring accurate diagnoses of ASD and confirming the absence of psychiatric disorders in TDC. Consents were obtained from every participant and their parents, ensuring ethical adherence. Participants were exposed to a series of emotional faces (happy, fearful, and neutral) during fMRI scans. The brain activities were compared between the ASD and TDC groups as they passively observed the stimuli. This detailed approach allowed the extraction of nuanced data relating to brain activation patterns in response to varying emotional stimuli. The results revealed distinct activation patterns in the ASD group, characterized by lower activation in several brain areas in response to all emotional faces compared to the TDC group. Specifically, exposure to fearful expressions led to decreased activity in the ASD group within the right amygdala, right superior temporal groove, and right inferior frontal region. Conversely, upon encountering joyful expressions, this group demonstrated diminished stimulation within the left insular cortex, left middle frontal gyrus, and right inferior frontal gyrus, and when faced with neutral expressions, a reduction in activation was perceived in the left posterior central region, left superior insular area, and right insula. Interestingly, the ASD group showed heightened activation in certain areas, notably the dorsal posterior cingulate region, left superior frontal area, and left inferior frontal groove for expressions of fear, and the right occipital gyrus and left superior temporal gyrus for joyful expressions. For neutral faces, elevated activation was recorded in the right parietal region, right precuneus, and the right middle frontal area as well. However, the analysis demonstrated no significant correlation between the brain responses and the total Social Responsiveness Scale score in subjects with ASD, hinting at the complexity of correlating neurological patterns with behavioral symptoms in ASD.

In the research undertaken by Neuhaus et al. focused on analyzing gender variances in children with ASD by examining resting-state EEG data. The participants were children aged between 8 and 17 years [8]. Out of the initially enrolled children, 280 provided valid, artifact-free EEG data. The selection of the participants was meticulously performed, excluding those with specific medical conditions, significant prenatal/perinatal complications, and those on certain medications. The acquisition process of EEG data involved allowing participants to acclimate to the EEG environment and offering them clear and concise instructions. The EEG session comprised watching short movies and resting the eyes, and it lasted approximately 60 minutes. Strict protocols were followed to filter and segment the acquired EEG data, removing artifacts and ensuring data integrity. The findings demonstrated noticeable variations according to the biological sex of the participants throughout all five EEG frequency bands. The discrepancies were notably evident and statistically meaningful in the central and posterior areas. Men showed power values that were between 10-57% higher in the central area and 34-61% higher in the posterior areas compared to females. There were observed interactions between sex and age, suggests that the association between biological gender and intensity might be influenced by age, particularly at higher frequencies in the anterior left area. Additionally, a clear correlation between age and power was discovered, with the power diminishing progressively with each successive year of age. In terms of diagnostic groups, differences that are statistically substantial were identified for the alpha frequency, with neurotypical youth displaying 20-46% greater power in all nine regions of interest compared to youth with ASD. Furthermore, a possible interrelation between diagnosis and gender was observed concerning gamma intensity at the left central region. In this context, females with ASD had something to do with 28% reduced intensity in comparison with neurotypical females.

Moreover, the research demonstrated notable associations between parent-observed socialization, evaluated using the Vineland-II, and the intensity in the theta, alpha, and beta frequencies. Particularly, participants possessing more robust socialization capabilities showed diminished EEG power in these frequencies. These correlations between EEG power and observable traits were mainly influenced by

the male subgroup with ASD, with the female group mostly displaying unrelated EEG power across frequencies to observed traits.

In the conducted study by Chanel et al., the researchers focused on comparing the efficiency of different movement correction methods, namely Friston24 and Rawrp6, in classifying brain activity, primarily using the SVM RFE feature selection algorithm [9]. Two series of tests were performed to evaluate the effect of feature selection on the classification accuracy of these methods. The results showed that without applying feature selection, the Friston24 method outperformed Rawrp6. However, when feature selection was incorporated, Rawrp6 saw a substantial improvement and exceeded the performance of Friston24. Moreover, the study identified that the most discriminative brain regions, responsible for social cognition and processing of faces and bodies, had reduced contribution in participants with ASD compared to controls. The research also employed a dimensional approach, centering on social motivation, and examined it through a range of questionnaires. A significant predictive relationship between social anhedonia scores and classification scores was found in one of the experiments pertaining to the group with ASD, emphasizing the pivotal role of social motivation in autism research. It was also concluded that anxiety states or traits didn't significantly influence the classification scores. The results highlight the significance of considering social motivation in autism research and demonstrate the efficacy of the Rawrp6 method when feature selection is applied.

4. The Effectiveness of Biofeedback Intervention for Children with ASD

In the study by Kouijzer et al., the effects and specifics of EEG- and SC-biofeedback on individuals with ASD symptoms were investigated [10]. And researchers undertook a series of comprehensive analyses. Participants, segmented into EEG- and SC-biofeedback groups, were subjected to a pre-defined number of sessions, with some being unable to complete due to various reasons like illness, leading to inclusion of diverse session completion in the analyses. Comparisons of the 19-channel electroencephalogram captures from participants against the Neuroguide database highlighted elevated delta and theta oscillations, especially within the frontal and central cerebral areas. The outcomes were instrumental in determining the specific scalp site and frequency bands employed during EEG-biofeedback sessions.

The participants demonstrated varying degrees of regulation abilities, with a few indicating an inverse relationship of delta and/or theta power throughout the sessions, recognized as EEG-regulators, while others, unable to manifest such correlations, were identified as SC-regulators or non-regulators. The assessments were based on the mean amplitudes during the biofeedback sessions. In assessing the impacts on ASD symptoms and executive functions, the data depicted no discernible specific effects of the biofeedback methodologies, however, EEG-regulators were seen to exhibit improvements in cognitive flexibility post-treatment, maintained six months later. Comparative analyses of the EEG and SC groups with a control group revealed no significant non-specific effects or differences in treatment expectancy. Examination of expectation of treatment data revealed no significant differences between the biofeedback and waiting list groups. Individuals on the standby roster were assured they would be provided with EEG- or SC-biofeedback post-research concluded. One the other part, the perceived unfulfilling impacts on the symptoms of ASD led to a decision by the school board to discontinue the biofeedback, with no requests for additional treatment from the participants.

5. Conclusion

The diverse research studies meticulously elucidate the nuanced neurological deviations associated with ASD, painting a comprehensive picture of its multifaceted nature. Significant findings include distinct variations in brain activation patterns, notably in regions critical for emotional processing and social cognition, and marked differences in EEG coherence and functional connectivity, especially in the alpha frequency band, between individuals with ASD and typically developing counterparts. For instance, specific studies depicted significant under-connectivity in males with ASD, especially in

the fusiform gyrus and thalamus, whereas females demonstrated patterns of hyper-connectivity, mainly in frontal regions. Moreover, the detailed analysis from multiple studies highlighted the significance of sex-based differences within ASD, reinforcing the importance of incorporating gender-inclusive perspectives in ASD research. These observed differences are crucial in understanding the diversity within the spectrum and indicate a substantial complexity in correlating neurological patterns with behavioral symptoms. The combined insights from these studies accentuate the value of discerning the intricate neurological and functional disparities in ASD, providing a refined lens through which tailored intervention and management strategies can be developed, thereby contributing to more personalized and effective approaches in addressing the diverse needs of individuals with ASD.

One of the limitations of previous studies is that the research predominantly incorporated children with high functioning ASD as the sample. While those with low functioning ASD were excluded. Apart from that, the small sample size included in the research is inadequate for the high-performance demands in analyzing brain networks, potentially obscuring subtle intergroup differences or developmental influences. Furthermore, the emphasis on classifying subjects against typically developed peers is insufficient to understand the nuances across the autism spectrum. Lastly, the scarcity of public fMRI and EEG data and the predominance of unimodal approaches constrain the study's comprehensive insight. Future studies should address these limitations to investigate this area more comprehensively.

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