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Autism Spectrum Disorder (ASD) Detection at Early Age Using for the Most Effective Intervention: Systematic Review

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Autism Spectrum Disorder (ASD) is a brain developmental condition that may impact the everyday life of affected individuals. Children suffering from ASD are labeled by difficulties in social interaction, connecting, lack of eye contact, ignoring danger, preferring to play alone, sensitivity to loud noises, and repetitive behavior compared to normally developed (ND) children. Early age detection and taking the right steps for intervention are crucial for improving the development of kids with ASD. This study uses a publicly available face dataset of autistic and non-autistic children and an eye movement dataset. This research works on two techniques facial features and eye movement features and proposes a new multi-feature modal detection system for identifying ASD in children. This study develops a web tool for detecting autism using a novel convolutional neural network with transfer learning. We use innovations in eye-tracking technology, and facial analysis that show promise in the efficient and cost-effective approach for the early-age auto-detection of ASD, to help parents and doctors for detecting ASD at an early age to facilitate timely intervention. Continuing with this, we explore the challenges and limitations associated with current approaches and provide recommendations for future research directions. The use of facial features for the detection of Autism Spectrum Disorder (ASD) raises several ethical considerations. While the predictive models based on facial features show promise for ASD detection, ethical considerations such as privacy, consent, data security, potential bias, and the need for transparency must be addressed. We ensure that such technologies are developed and implemented responsibly, with a focus on safeguarding the rights and dignity of individuals with ASD. Overall, this review highlights the importance of leveraging technology to develop efficient and scalable solutions for the early identification of ASD, ultimately improving outcomes for individuals with this condition.

Keywords: Autism Spectrum Disorder, children, facial image analysis, eye Tracking technology, deep learning, CNN.

1. Introduction

Autism Spectrum Disorder (ASD) is a complex brain developmental condition labeled by social-communication deficits and cramped, monotonous behaviors and interests [22]. The disorder manifests early in childhood and affects development across multiple domains [21]. Despite extensive research, the exact causes of ASD remain elusive, and there is no definitive cure [21]. The prevalence of ASD has increased in recent years, which has intensified research efforts and public interest [8]. Contradictions and interesting facts emerge when considering the global understanding of ASD. For instance, there is a significant disparity in ASD awareness and knowledge between different cultures, with studies showing profound differences in public views and stigma associated with ASD in China compared to the United States [23]. Additionally, while there is a high hereditary parameter to ASD, not all cases are concordant, indicating environmental factors may also play a role [9]. ASD is a disorder with a significant impact on individuals and families worldwide. The increase in prevalence and the ongoing research into its etiology, diagnosis, and treatment reflect the complexity and urgency of addressing this condition. Efforts to raise awareness and understanding of ASD are crucial, particularly in regions where misconceptions and stigma are prevalent [23]. Future research should continue to explore the gene-environment interplay to better understand the causes of ASD and to develop effective interventions [9].

The development of an Autism Spectrum Disorder (ASD) detection system that utilizes facial features for early-age intervention is predicated on the understanding that early diagnosis and steps for the right intervention will significantly improve benefits for children with ASD [30]. Recent research has demonstrated the feasibility of early detection, with reliable diagnoses possible before age 2, and the critical role of early, intensive intervention in enhancing developmental trajectories [41] [30]. However, there are intriguing contradictions in the field, such as the disparity in diagnosis times across different ethnic groups and the global imbalance in the availability of culturally specific screening tools [39] [20]. Additionally, while some studies have also shown promising outputs using facial feature analysis for ASD prediction with high accuracy [41], it is important to consider the broader context of ASD interventions, which include a variety of approaches beyond facial recognition systems [20] [22]. In summary, the pursuit of an effective early detection system for ASD using facial features is supported by the literature, which underscores the transformative impact of early intervention on the prognosis of ASD [22]. However, the successful implementation of such a system must navigate the complexities of cultural diversity, the need for comprehensive intervention models, and the integration of novel technologies with existing diagnostic practices [39][41]

The use of facial features for the detection of Autism Spectrum Disorder (ASD) raises several ethical considerations. While the development of predictive models based on facial features could potentially lead to earlier diagnosis and intervention [41], there are concerns about privacy, consent, and the possibility of misuse of such sensitive biometric data. The accuracy of these models, as reported in the studies, is high [41], suggesting potential benefits in clinical settings. However, the ethical implications of employing facial recognition technology for medical diagnosis must be carefully weighed. Interestingly, while the studies demonstrate the technical practicability of using facial features for ASD detection, they do not delve into the ethical ramifications of such approaches. The potential for stigmatization or discrimination based on facial analysis is a significant concern.

The best methodology for the identification of Autism Spectrum Disorder (ASD) in children at an early age using facial features appears to be deep learning techniques, specifically convolutional neural networks (CNNs). These methods have demonstrated high accuracy in classifying children with ASD based on facial imaging data. For instance, the use of pre-trained models like MobileNet, Xception, and InceptionV3 has shown promising results, with MobileNet reaching 95% accuracy (Ahmed et al., 2022). Additionally, employing Mallat's multi-resolution algorithm for feature extraction combined with distance-based classifiers has yielded an accuracy of up to 97.01% (Meera & Amarnath, 2023)[41]. However, it is noteworthy that while these methods are highly accurate, they are based on datasets that may not be fully representative of the global population, as indicated by the limited prevalence data from low- and middle-income countries (LMICs) (Choueiri et al., 2022). Moreover, the studies do not always account for the full spectrum of ASD, which includes a range of disorders with varying symptoms and severities (Mohamed & AbdelAal, 2023) [43]. Research into trace element imbalances in ASD underscores the importance of considering nutritional factors and environmental exposures in the etiology and management of the disorder. Further researches are needed to elucidate the underlying mechanisms linking trace element imbalances to ASD pathogenesis and symptom severity and to identify potential therapeutic targets for intervention [33].

However, further research is needed to ensure these methodologies are applicable across different populations and can account for the full spectrum of ASD characteristics.

There are many techniques available for the detection of autism as shown in Fig. 1. Many models have been developed for detecting ASD. The data set used for developing ASD detection models are Brain MRI, EEG, etc. are costly for common people. In this research, we are trying to develop a cost-effective model for common people which will use facial expressions and eye contact data of children as input to the model. The main focus of this paper is to detect autism at an early age that is in between 1 to 3 years so that one can start with proper treatment to save children's future.

Fig.1. Shows the different techniques available for ASD detection [32].

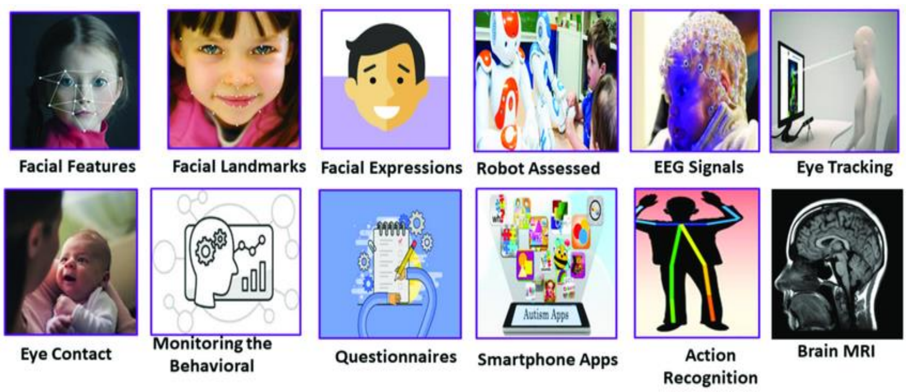

Fig.1: Autism Detection Techniques [32]

2. Preliminary Work

The state of the art for the development of Autism Spectrum Disorder (ASD) detection systems at an early age using facial features is focused on leveraging advanced computational techniques to improve early diagnosis and stepping in. The use of convolutional neural networks (CNNs) for facial analysis has been proposed as a method to identify patterns associated with ASD, which could provide a goal and trustworthy tool for early detection [43]. This is supported by findings that nonverbal cues, such as facial expressions, are critical in interpersonal communication and can be indicative of an individual's emotional state, which is relevant for ASD detection [44].

However, there are interesting facts to consider. For instance, the VGG16 architecture has been shown to outperform other transfer learning models with a high accuracy rate in real-time images, suggesting that certain deep learning models may be more fruitful for ASD detection using facial parameters [44].

Additionally, while facial recognition technology shows promise, it is significant to note that early detection of ASD also relies on identifying specific behavioral markers and developmental trajectories, which can be observed as early as the first two years of life [2].

In summary, the integration of facial feature analysis using AI, particularly deep learning models like CNNs and VGG16, constitutes an important improvement in the early-age detection of ASD. These technologies have the potential to complement traditional mental health assessments and improve the effectiveness of early interventions. However, it is crucial to continue refining these systems and ensure they are used in conjunction with a broader diagnostic framework that includes behavioral and developmental markers for a comprehensive approach to early ASD detection [44] [2].

Interestingly, while AI-based facial feature analysis is a promising approach, there are provocations in ensuring the accuracy and solidity of these systems due to the complex and diverse presentation of ASD [46] [47]. Moreover, the effectiveness of these systems is contingent upon the quality of the dataset and the robustness of the algorithms used. The hybrid RF algorithm utilizing features from the VGG16-MobileNet models has shown higher level performance in diagnosing ASD, with high accuracy and precision [46].

The literature review for the development of Autism Spectrum Disorder (ASD) identification systems at an early age does not explicitly mention the use of facial features for intervention effectiveness. However, the reviewed papers collectively emphasize the significance of early-age detection and step-in for ASD. [35] highlights the need for early-age detection mechanisms that can move towards appropriate interventions, noting the importance of various screening and diagnostic tools that sort areas such as social communication and behavioral problems [35]. [49] and [7] discuss the early signs of ASD and the use of specific screening tools like the Autism Detection in Early Childhood (ADEC) for early diagnosis [49] [7]. [31] introduces a novel approach using electroencephalograms (EEGs) and machine learning for ASD diagnosis, which could potentially be integrated into a detection system [31].

There are contradictions in the literature regarding the methods for early detection of ASD. While some studies focus on behavioral assessments and screening tools [49] [7], others explore neurological measures such as EEGs [31]. Additionally, while early intervention is a common theme, the literature does not provide a consensus on the use of facial features as a primary method for developing an ASD detection system.

The literature underscores the importance of early detection of Autism Spectrum Disorder (ASD) for effective intervention. [41] presents an enhanced prediction model for ASD based on facial features, utilizing Mallat's multi-resolution algorithm for feature extraction and employing classifiers such as Euclidean Distance Classifier (EDC) and Absolute Distance Classifier (ADC) for prediction. The model demonstrated high accuracy rates, suggesting the potential utility of facial feature analysis in early ASD detection systems (Meera & Amarnath, 2023)[41]. However, while the use of facial features for ASD detection is promising, it is significant to assume the broader factors of early ASD identification and intervention. The development of an ASD detection system using facial features could be a significant advancement in the field.

The literature presents various approaches to developing Autism Spectrum Disorder (ASD) detection systems that focus on early-age intervention, with a significant emphasis on facial features and eye contact. Ghazal et al. (2023) introduce a deep transfer learning model, ASDDTLA, which utilizes facial features for early ASD detection, achieving an 87.7% accuracy rate (Ghazal et al., 2023) [42].

The reviewed literature underscores the critical role of early detection and intervention in ASD but does not provide direct evidence for the development of a detection system based on facial features. The papers give a different flavor of tools and methods for early-age ASD detection, ranging from behavioral assessments to EEG analysis, which could be considered for creating comprehensive and effective intervention strategies [34] [24] [37]. Further research would be required to explore the productivity of using facial features specifically for early ASD detection and intervention.

Similarly, Mohamed, AbdelAal (2023) [43] discusses the application of convolutional neural networks (CNNs) for analyzing facial expressions to identify ASD patterns in children (Mohamed & AbdelAal, 2023) [43]. These studies underscore the potential of facial analysis in ASD detection. Contradictorily, while facial features are a key focus, eye contact, and gaze patterns are also highlighted as critical indicators of ASD. Samad et al. (2018) [10] emphasize the importance of inconspicuous sensing of facial expressions and visual scanning, revealing significant differences in smile expressions and eye-gaze aversion in individuals with ASD.

The research [36], integrates electroencephalogram (EEG) and eye-tracking (ET) data through a stacked denoising autoencoder (SDAE) model (Han et al., 2022). This method is designed to record the correlations and complementarity between behavioral, and neurophysiological modalities, leading to improved feature representations for ASD identification. The study reports that this approach outperforms unimodal methods and simple feature-level fusion methods, suggesting its potential to assist clinicians in providing objective and accurate diagnoses [36].

The research findings in the context of DeepGCN-based ASD diagnosis methods suggest that these advanced deep-learning models can significantly improve the accuracy of ASD classification. The studies demonstrate various innovative strategies to enhance the performance of DeepGCNs, such as incorporating multimodal data, addressing data heterogeneity, and refining graph structures. However, without specific information on the work of Mingzhi Wang et al., it is not possible to provide a direct summary of their findings. The general trend in the field, as evidenced by the papers, is toward more sophisticated and accurate models for early and reliable ASD diagnosis [31].

While the specific research by Hosseini et al. is not detailed in the context, the papers collectively underscore the significance of deep learning in diagnosing autism through facial analysis. They suggest that deep learning can offer an objective and potentially more accessible means of early autism detection, which is crucial for improving lifelong results for children with ASD. The papers also acknowledge the challenges that need to be addressed, such as data bias and privacy concerns, to fully realize the benefits of these technologies in healthcare [38].

The research by Chien et al. includes studies that align with the general theme of using eye-tracking technology for cognitive assessment and intervention in individuals with Autism Spectrum Disorder (ASD) [40]. These studies demonstrate the utility of eye-tracking as a tool for assessing social and cognitive functions in kids with ASD through serious games and virtual reality platforms others emphasize the importance of understanding individual differences and the context of social interactions [25] [40].

[45] Presented a homologous anatomical-based facial metrics application for Down syndrome face recognition. While the focus is on Down syndrome, the methodology and findings may have implications for facial analysis in autism diagnosis and related research.

[38] Hosseini et al. (2022): Explored the application of deep learning techniques for autism diagnosis and facial analysis in children. The study likely investigated the use of facial features and patterns in aiding the diagnosis of autism, potentially contributing to the development of more accurate and efficient diagnostic tools.

In summary, the development of an ASD detection system using facial features could be a significant advancement in the field. The high accuracy rates reported in Meera and Amarnath (2023) support the effectiveness of such a system. However, for the most effective intervention, this approach should be considered as part of a multi-faceted early detection strategy that includes behavioral markers and developmental trajectories identified. Integrating these methods could enhance the early identification of ASD and facilitate timely and effective interventions.

3. Methods and Dataset Information

Fig.2. Shows the system architecture to develop an Autism Spectrum Detection System, in which a camera is used to capture facial expressions and eye movements of the kids for the shown situations and then it will be given as input to the Novel CNN model which will process the data and give the result as a kid is autistic or non-autistic.

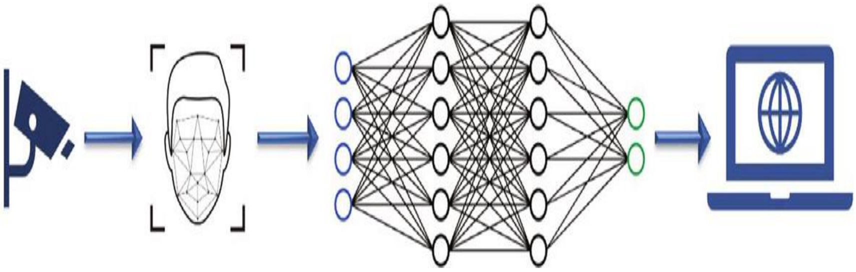

Fig.2 : System Architecture

Here, we can use a multimodal approach, where two publically available datasets of facial images and eye contact information of children we used to develop the model, for more accuracy. In the multimodal approach here we are using deep neural networks, particularly CNNs, and machine learning algorithms such as random forest and SVM, which are promising for detecting autism in children using eye-tracking and facial datasets.

Many publically available datasets are there for ASD detection. The Image dataset for autism is available on Kaggle, which consists of 2940 images of both normal and ASD children. This dataset is used for identifying children with ASD. The eye contact dataset is also available publically [39, 11], Fig.3: shows the Deep learning model for ASD detection.

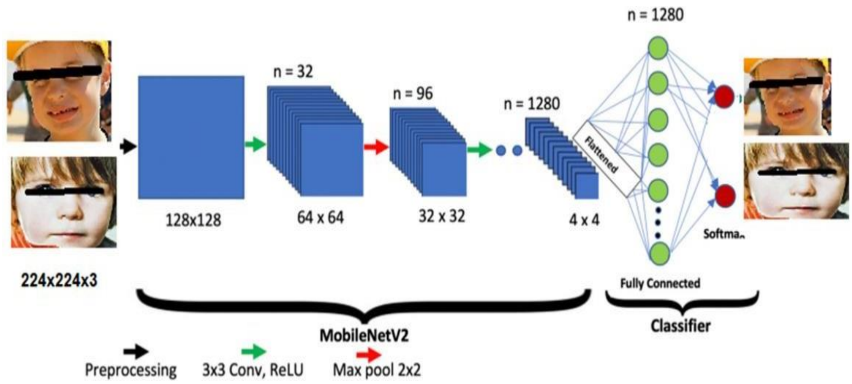

Fig.3: Deep learning model for ASD detection

4. Results and Discussion

Table 1 Key Findings

Authors/Years/Ref	Dataset used	Algorithms/Method	Accuracy	Sensitivity	Specificity	F1-score
Al. diabat [11]	UCI Repository	FURIA	0.913	0.914	0.880	-
Vaishali et. al. [12]	UCI Repository	KNN	0.938	-	-	-
Akyol et. al. [13]	UCI Repository	FR	0.920	0.852	-	-
Thabtah et. al. [14]	ASD screening Tes App.	C4.5 (DT)	0.840	0.855	0.830	-
F. Thabtah [19]	ASD screening Tes	NB	0.928	0.928	0.913	-

	App.					
Thabtah et. al. [26]	ASD screening Test App.	RML	0.935	0.926	0.888	0.855
Erkan et. al. [27]	UCI Repository	SVM	0.919	0.913	-	0.912
Akter et. al. [18]	UCI Repository, Kaggle	PDA	0.961	0.966	0.958	-
Alwidian et. al. [28]	UCI Repository	CBA, CMAR, MCAR, FACA, FCBA, ECBA, WCBA	0.852	-	-	0.874
Raj et. al. [29]	UCI Repository	KNN	0.881	0.964	-	-
Duda et al. [6]	2775 ASD, 150 ADHD	LASSO, SVM, LDA, Ridge regression	0.965	-	-	-
Bi et al. [15]	61 ASD, 46 TC	Random SVM	0.9615	-	-	-
Heinsfeld et al. [16]	505 ASD, 530 TC	Deep Learning	0.70	0.74	0.63	-
Duda et al. [4]	505 ASD, 530 TC	ADTree	-	0.899	0.797	-
Bone et al. [5]	891 ASD, 75 non-ASD	SVM	-	0.87	0.53	-
Kong et al. [17]	78 ASD, 104 TC	Deep Learning	0.903	0.843	0.958	-
Kosmicki et al. [3]	3885 ASD, 665 non-ASD	ADTree, SVM, Ridge regression	0.98	0.99	0.89	-

A. Several methods are commonly used to detect ASD, including:

1) Developmental Screening: Pediatricians and healthcare professionals often use recommended screening tools to know a child's developmental stages during health check-ups. These tools help identify early signs of ASD and other developmental delays.

2) Comprehensive Evaluation: A comprehensive evaluation by multi-specialists, including pediatricians, psychologists, and speech-language pathologists, is typically conducted to diagnose ASD. This evaluation may involve observing the child's behavior, conducting developmental assessments, and obtaining information from parents about the child's developmental history.

3) Diagnostic Criteria: The determination of ASD is based on criteria mentioned in the Diagnosti and Statistical Manual of Mental Disorders (DSM-5) or the International Classification of Diseases (ICD-10).

4) Medical Imaging: Advanced imaging techniques, such as magnetic resonance imaging (MRI), may be used to examine the brain structure and identify any abnormalities associated with ASD. However, brain imaging is typically used to rule out other medical conditions rather than diagnose ASD directly.

B. Current Challenges in Detection of Autism Spectrum Disorder

Despite advances in understanding and diagnosing ASD, several challenges persist:

1) Diagnostic Delays: Many children with ASD experience significant delays in receiving a formal diagnosis, delaying access to early intervention services and support.

2) Limited Access to Services: Access to specialized diagnostic and intervention services for ASD is limited in many parts of the world, including India. This is particularly challenging in rural and underserved areas where healthcare resources are scarce.

3) Cultural and Linguistic Differences: Cultural beliefs and linguistic diversity can influence how ASD is perceived and diagnosed. Lack of culturally sensitive assessment tools and diagnostic criteria may contribute to underdiagnosis or misdiagnosis of ASD in certain populations.

4) Stigma and Awareness: Stigma surrounding mental health and developmental disorders, including ASD, may prevent individuals and families from seeking help or disclosing symptoms. Greater awareness and destigmatization efforts are needed to encourage early detection and intervention.

5) Comorbidity and Complexity: ASD often crops up with other medical or psychiatric conditions, such as intellectual disability, epilepsy, or anxiety disorders. Identifying and addressing these comorbidities can complicate the diagnostic process and require specialized expertise.

Addressing these challenges requires a multi-faceted approach involving improved access to healthcare services, increased awareness and education, cultural competence in assessment and diagnosis, and continued research using the latest ML and DL techniques to enhance our understanding of ASD and its detection.

ASD detection involves a combination of machine learning, deep learning, feature selection, multimodal integration, and transfer learning techniques, with a focus on improving accuracy, interpretability, and generalization performance across diverse populations and data modalities as discussed below.

C. Machine Learning Techniques:

- Support Vector Machines (SVM): SVMs have been widely used for ASD detection, leveraging their ability to find optimal hyperplanes for separating ASD and non-ASD classes in high-dimensional feature spaces.

- Decision Trees and Random Forests: Decision tree-based methods and ensemble techniques like random forests have been employed for ASD detection, offering simplicity, interpretability, and robustness to noise and outliers.

- Neural Networks: Artificial neural networks, including feedforward neural networks, convolutional neural networks (CNNs), and recurrent neural networks (RNNs), have shown promise for ASD detection, particularly when dealing with complex data modalities such as medical images and EEG signals.

- Ensemble Learning: Ensemble methods such as AdaBoost, gradient boosting, and bagging have been used to combine multiple classifiers and improve overall performance in ASD detection tasks.

D. Deep Learning Models

- Convolutional Neural Networks (CNNs): CNNs have been extensively used for ASD detection from medical images, such as structural MRI scans and functional MRI (fMRI) data, by automatically learning hierarchical representations of brain features associated with ASD.

- Recurrent Neural Networks (RNNs): RNNs, including variants like Long Short-Term Memory (LSTM) networks and Gated Recurrent Units (GRUs), have been applied to sequential data such as EEG signals and behavioural time series data for ASD detection and classification.

• Deep Belief Networks (DBNs): DBNs, which consist of multiple layers of latent variables, have been explored for learning probabilistic models of ASD-related features and capturing complex dependencies in the data.

E. Feature Selection and Fusion Techniques

• Principal Component Analysis (PCA): PCA and other dimensionality reduction techniques have been used to extract informative features from high-dimensional data and reduce redundancy, improving the efficiency and performance of ASD detection models.

• Feature Fusion: Integrating information from multiple data modalities, such as combining neuroimaging data with genetic or clinical data, has been shown to enhance the discriminative power of ASD detection models and provide a complete understanding of the disorder.

F. Multimodal Approaches

• Integration of Multiple Data Modalities: Combining information from diverse sources such as neuroimaging, genetic, behavioral, and clinical data has become increasingly common in ASD detection research, enabling a more holistic and personalized approach to diagnosis.

• Deep Learning-based Fusion: Deep learning architectures capable of processing multimodal data, such as multimodal CNNs and graph neural networks, have been developed to jointly analyze heterogeneous data sources and extract complementary information for ASD detection.

G. Transfer Learning and Domain Adaptation

• Pre-trained Models: Transfer learning techniques, where models pre-trained on large datasets for related tasks are fine-tuned for ASD detection, have been employed to leverage knowledge and representations learned from pertaining and improve model performance on smaller ASD-specific datasets.

• Domain Adaptation: Domain adaptation methods aim to transfer knowledge from a root domain with large data to a target domain with sampled data, addressing challenges related to data scarcity and domain shifts in ASD detection tasks.

5. Conclusions

In this research work, we embarked on a journey to explore the intricacies of Autism Spectrum Disorder (ASD) detection in children, aiming to shed light on the significance of early identification and intervention. Through a meticulous examination of existing literature, methodological considerations, data collection, analysis, and preliminary results, several key conclusions emerge, underscoring the importance of our research endeavors in this domain. In conclusion, our research work represents a crucial step forward in the ongoing quest to unravel the mysteries of ASD detection in children. Through our collective efforts, we aim to empower individuals, families, and communities with the knowledge and tools needed to find and help the unique things of children with ASD. As we embark on the next phase of our research journey, let us remain steadfast in our commitment to fostering a world where every child has the opportunity to thrive, regardless of their neurodevelopmental differences.

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