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Diagnostic Classification of ASD Using Fractal Functional Connectivity of fMRI and Logistic Regression

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Abstract. Our study used functional magnetic resonance imaging and fractal functional connectivity (FC) methods to analyze the brain networks of Autism Spectrum Disorder (ASD) and typically developing participants using data available on ABIDE databases. Blood-Oxygen-Level-Dependent time series were extracted from 236 regions of interest of cortical, subcortical, and cerebellar regions using Gordon's, Harvard Oxford, and Diedrichsen atlases respectively. We computed the fractal FC matrices which resulted in 27,730 features, ranked using XGBoost feature ranking. Logistic regression classifiers were used to analyze the performance of the top 0.1%, 0.3%, 0.5%, 0.7%, 1%, 2%, and 3% of FC metrics. Results showed that 0.5% percentile features performed better, with average 5-fold accuracy of 94%. The study identified significant contributions from dorsal attention (14.75%), cingulo-opercular task control (14.39%), and visual networks (12.59%). This study could be used as an essential brain FC method to diagnose ASD.

Keywords. Autism spectrum disorder, functional magnetic resonance imaging, fractal functional connectivity, logistic regression

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder that affects social interaction and communication. It is characterized by delayed and disordered language, limited and stereotypical patterns of behavior, interests, and activities, and onset before the age of three. The complexities of ASD make the diagnosis challenging, and identifying a biomarker linked to ASD is crucial for early detection and targeted treatment. Several neuroimaging studies have used non-invasive brain imaging modalities, including structural magnetic resonance imaging (sMRI), electroencephalogram (EEG), magnetoencephalography, and diffusion tensor imaging, but functional magnetic resonance imaging (fMRI) [1] is one of the most promising modalities.

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fMRI signals have a higher spatial resolution than EEG [2] and can better study functional connectivity (FC) between different brain regions. In previous studies, many FC modeling methods have been proposed to construct brain functional networks, including Pearson correlation, Pearson partial correlation, Spearman's rank correlation coefficient, and Gaussian covariance. Resting-state fMRI signals follow fractal behavior, also known as long-range dependence, and they exhibit self-similarity and power-law scaling properties in the time and frequency domain, respectively [3]. Our study utilized the fractal property of fMRI signal to classify ASD and typically developing (TD) participants using XGBoost and logistic regression classifier to find corresponding brain networks.

2. Methods

The process pipeline followed in this study is shown in Figure 1.

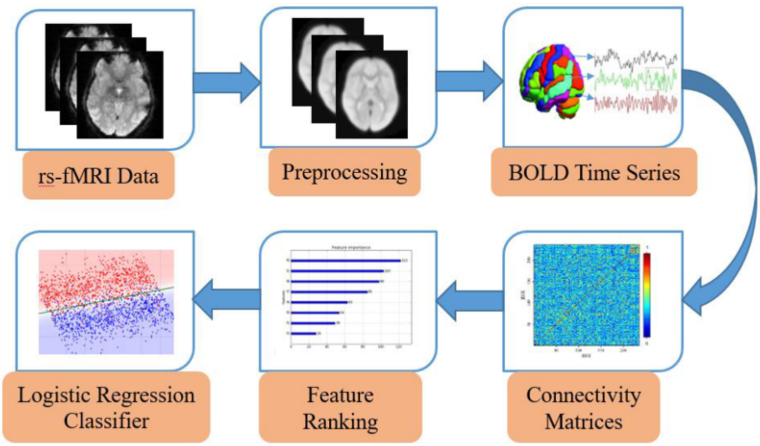


Figure 1. Process pipeline of the study

The fMRI data used in this study were obtained from the publicly available Autism Brain Imaging Data Exchange (ABIDE) database [4]. We considered the fMRI data (ASD=47, TD=125) from the KKI site for our analysis. The demographic information of the participants considered in this study is shown in Table 1. Initially, the fMRI data were preprocessed using the standard pipeline. We created a whole-brain mask by identifying the brain's voxels, which includes the BOLD signal in 95% of participants. For our study, we used 215 cortical ROIs from Gordon's, 14 subcortical ROIs from Harvard Oxford, and 7 cerebellar ROIs from Diedrichsen atlases. We extracted blood-oxygen-level-dependent (BOLD) time series from selected 236 ROIs. We studied the interaction between the brain regions using fractal FC which is the wavelet correlation of a multi-variate long memory process [5]. For each participant, we obtained an FC matrix of size 236x236 which yields 27,730 diagnostic features from the lower or upper triangular of the FC matrix. These features were ranked using the XGBoost feature ranking algorithm [6]. We analyzed the performance of the top 0.1%, 0.3%, 0.5%, 0.7%, 1%, 2%, and 3% features by 5-fold cross-validation using logistic regression as a classifier.

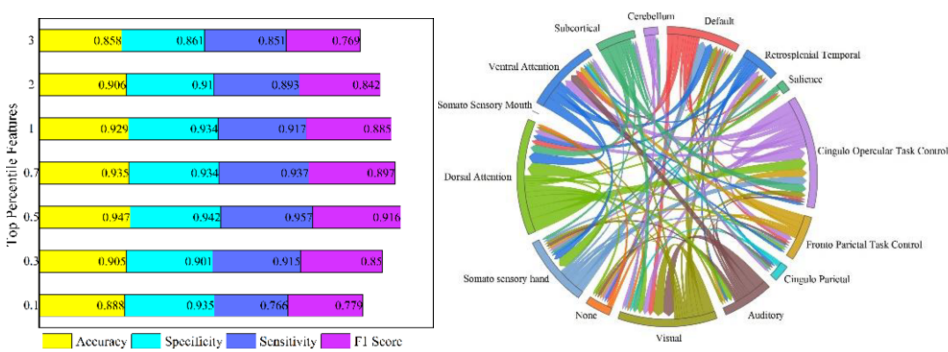
Table 1. Demographic information of the participants

	ASD	TD	*p*-value (2 sample t-test)
N (Handedness)	39(R),2(L),2(M)	109(R),8(L),8(M)	-
Males (Females)	34(13)	88(37)	-
Age in years	10.45±1.28	10.45±1.28	0.47
Motion	0.12±0.04	0.10±0.03	0.007
PIQ/FIQ	115±10	99±21	0.015

(PIQ: Performance Intelligence Quotient, FIQ : Full Scale Intelligence Quotient)

3. Results and Discussions

Figure 2 (a) shows the classification performance of 0.1%, 0.3%, 0.5%, 0.7%, 1%, 2%, and 3% features obtained by the XGBoost feature ranking algorithm. Performance increases up to 0.5% features and then decreases. We achieved average 5-fold cross-validation accuracy of 94% for 0.5% features. Other parameters such as specificity, sensitivity, and F1 score were also better for 0.5% features.



(a) **(b)**

Figure 2. (a) Performance of LR classifier for different percentile fractal FC features ranked using XGBoost **(b)** Connectome of top brain networks corresponding to 0.5% fractal FC features

The connectome of top networks that contributed to classification is shown in Figure 2 (b). Cord thickness serves as a proxy for connection occurrence rates. Our results show that the connections within dorsal attention, within visual, and within cingulo-opercular task control were the top dominant intra-network connections. Moreover, inter-network connections from dorsal attention to cingulo-opercular task control, ventral attention to dorsal attention, dorsal attention to somato sensory hand, and auditory to visual were dominant. The connections from dorsal attention contributed a significant percentage (14.75%), followed by cingulo-opercular task control (14.39%) and visual (12.59%).

4. Limitations and Future Work

In our study, we have considered data from only one site and it includes a limited number of participants. However, more research must be conducted with a large dataset before it can be applied to clinical diagnosis. Also, the performance of the fractal FC method needs to be compared with already existing FC methods like Pearson correlation. Furthermore, deep learning methods can be used to enhance classification performance.

5. Conclusions

In conclusion, our study proves that fractal FC can be an effective method for the diagnosis of ASD. We evaluated the effect of different numbers of fractal FC features on the performance of the classifier and observed that 0.5% of top features give better classification results. The classification model constructed using the logistic regression algorithm achieves 94% accuracy. Classification accuracy was low for a smaller number of features as well as for a greater number of features it was the maximum for the optimal number of features. This study could in the future, potentially be helpful in the diagnosis of neurodevelopmental disorders.

6. Acknowledgment

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