Supplementary file of Diagnosis of Schizophrenia: A comprehensive evaluation

I. Classification Algorithms

The classification algorithms evaluated in this study for diagnosis of schizophrenia are explained below. Let the training set be $((x_1, y_1), \cdots, (x_N, y_N))$ where N is the total number of training examples. X is the feature matrix $[x_1, x_2, \cdots, x_N]$ of size $N \times d$ and Y = $[1, 2, \cdots, m]$ is a $N \times 1$ vector of class labels.

A. Heterogeneous Random Forest

Even though some of the oblique random forest based [1] on linear classifier perform better consistently, they aren't always the best variant of oblique random forest for every dataset. Heterogeneous RaF [2] uses several linear classifiers for generating the separating of hyperplanes. Even when some of the linear classifier based variants have lower ranks, they can still be integrated forming a heterogeneous linear classifier based oblique random forest. This would require us to evaluate n classifiers in K binary partitions, hence requiring nK number of evaluations at each node. They employed a hyper class based partitioning with one-vs-all partitioning using multiple linear classifiers at each node.

The six different classifiers which have been employed are Support Vector Machines (SVM), Multisurface Proximal SVM (MPSVM), Linear Discriminant Analysis (LDA), Least Squares SVM (LSSVM), Ridge Regression (RR) and Logistic Regression (LR) as they have performed well in several domains [3].

For the decision trees, each split is rated based on impurity criterion. All the splits at each non-leaf nodes are linked with an impurity measure Gini Index. The one which is having the maximum value is the selected split for that particular node. Instead of looking for optimal oblique split in whole search space, the recursive partitioning property exhibited by decision trees, generating few oblique splits and used their $g(i)$ for selecting the best oblique split.

The ideal gini score (g_i) is the one which is obtained when all the samples of one class are perfectly seperated from other class by an oblique split. By training the linear classifiers on partitions with higher g_i and are likely to give higher g. One can ignore the partitions with lower g_i which are likely to give lower g.

In an ideal setting assuming that the partitions are well separated, g_i gives us a measure of the purity of the child node. This ideal setting however is not true in practical environment and a partition could have high g_i and low g if the partitions are hard to separate. Hence comes the cluster validity index which aims to identify the sets of clusters that are well separated and compact. Dunn index(DI) is one such cluster validity index. For k clusters, it can be defined as :

$$\min_{i=1,\ldots,k} \left[\min_{i=i+1,\ldots,k} \left(\frac{diss(c_i, c_j)}{max_{m=1,\ldots,k} diam(c_m)} \right) \right] \quad (1)$$

Here $diss(c_i, c_j) = min_{x \epsilon c_i, y \epsilon c_j} ||x - y||$ is the dissimilarity between cluster c_i and c_j and $diam(c) = max_{x,y \epsilon C} ||x - y||$ is the intra cluster function. We use Bhattacharyya distance as the metric for distance.

B. Kernel Ridge Regression

Kernel Ridge Regression [4] and SVM [5] are the best known members using kernel method. Kernel based methods are very useful when there is non-linear structure in data. KRR is faster to train and simpler with its closed form solution and can achieve performance which is comparable to complex methods such as SVM.

The kernel ridge regression method is based on Ridge Regression [6] and Ordinary Least Squares. The OLS minimizes the loss $\min_{\beta} ||Y - X\beta||^2$ which is the L_2 norm. A shrinkage parameter λ is added to control the trade-off between variance and bias in the above expression giving us the following problem.

$$\min_{\beta} ||Y - X\beta||^2 + \lambda ||\beta||^2 \quad (2)$$

The closed form solution for above can be problem given as $\beta = (X^T X + \lambda I)^{-1} X^T Y$. The label predicted for the new unlabeled example x is given as $\beta^T x$. The Kernel ridge regression method extends linear regression into non-linear and high-dimensional space. The data which is present in X is replaced with the feature vectors :$x_i \rightarrow \phi = \phi(x_i)$ induced by the kernel where $K_{ij} = k(x_i, x_j) = \phi(x_i)\phi(x_j)$. Hence the new predicted class label for the new example x is given as :

$$Y^T (K + \lambda I)^{-1} k \quad (3)$$

Here $k = (k_1, k_2, ...k_N)^T$, $k_n = x_n.x$ and $n = 1, 2, ...N$.

C. Random vector functional link network (RVFL) [7]

RVFL [7] is the randomized version of the functional link neural network. Here, the input layer to the hidden layer, the weights are generated randomly in a suitable domain and fixed in the learning stage. Weights are generated in this manner ensuring that the activation functions $g(a_j^T x + b_j)$ are not all saturated. All weights are generated with uniform distribution within $[-S, +S]$. Here S is a scale factor which is determined

at the stage of parameter tuning. Only the output weights need to be determined by solving the problem :

$$y_i = d_i^T \beta, \quad i = 1, 2, ...N \tag{4}$$

Here P is the number of data samples, t is the target and d is the vectorised concatenation of random and the original features. Least squares can be used as a regularization technique in order to avoid over-fitting and obtain the solution. The two classes of RVFL algorithm are iterative RVFL, which obtains the output weights in an iterative manner based on the gradient of the error function and the closed-form based RVFL, which obtains the output weights in a single-step. The closed-form based RVFL exhibits a higher efficiency. L2 norm regularized least square is used to solve the following problem :

$$\sum_i (y_i - d_i^T \beta)^2 + \lambda ||\beta||^2 \ ; \ i = 1, 2, \cdots, N \tag{5}$$

The solution for the same is given as $\beta = D(D^T D + \lambda I)^{-1} Y$, where λ is the regularization parameter to be tuned. D and Y are the stacked features and targets of all the data samples in matrix form.

D. Random vector functional link network with AutoEncoder (RVFLAE) [8]

Autoencoder is an unsupervised learning model for which the output and input layers share the same neurons in order to reconstruct its own inputs instead of predicting target values for given input data. Sparse pre-trained RVFL is the unsupervised parameter learning method for RVFL. A sparse autoencoder is used to learn appropriate network parameters, which are developed via l_1 norm optimization instead of the usual l_2 norm. This means that more informative features will be retained to participate in the subsequent learning processes. During the learning process, the sparse autoencoder captures the excellent features in the encoding stage and learns the output weights in the decoding stage. Let the input data be X, then the sparse autoencoder has optimization problem given as :

$$O_w = arg\ min\{||\tilde{H}\bar{\omega} - X||^2 + ||\bar{\omega}||_{l_1}\}$$

Here $\tilde{H} \in \mathbb{R}^{N \times L}$ is the output matrix of hidden layer obtained via random feature mapping. $\bar{\omega} \in \mathbb{R}^{L \times d}$ is the output weight matrix of the sparse encoder. $||\tilde{H}\bar{\omega} - X||^2$ measures the loss to model the reconstruction process of input data and $||\bar{\omega}||_{l_1}$ is the l_1 norm regularization. The solution of this optimization problem is given by Fast iterative shrinkage threshold algorithm (FISTA) [9].

E. K nearest neighbours

K nearest neighbours algorithm assigns the label depending upon the similarity of the point with its neighbours. A constant K is first chosen for the algorithm. The Euclidean distance of the given point is calculated and the K nearest members are selected from it. The number of data points is counted and assign data points is assigned to the category for which there are maximum number of neighbours.

TABLE S-1: Evaluation of classification models based on AUCs with White Matter (900 features).

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	67.98	67.29	83.68	68.51	69.14	67.58	51.23
KNN	54.06	65.40	74.88	56.24	54.97	61.32	45.83
KRR (Linear)	65.89	70.42	73.66	72.47	72.47	55.03	54.55
KRR (Non-Linear)	65.33	67.42	73.99	71.09	71.16	68.72	53.91
LSTWSVM (Linear)	57.12	59.69	68.22	64.65	63.65	57.70	55.08
LSTWSVM (Non-Linear)	60.46	68.59	88.54	81.65	78.00	65.92	51.61
MPRaF-N	63.58	67.71	73.03	70.68	64.32	66.26	51.37
MPRaF-P	66.22	65.37	69.60	70.41	66.44	67.62	51.73
MPRaF-T	63.24	56.94	74.54	66.13	67.04	57.01	49.59
Neural	56.04	66.26	81.91	64.33	62.41	61.68	46.55
pinGTSVM	55.79	59.00	73.80	69.54	67.77	50.10	48.29
RaF-LDA	57.84	64.84	76.26	62.86	67.88	67.21	49.74
RaF-PCA	62.54	68.72	72.11	67.53	64.95	62.84	47.04
RaF	62.23	64.18	71.27	69.59	63.84	69.42	51.38
RELSTSVM (Linear)	59.79	73.62	73.81	75.69	75.69	68.77	61.61
RELSTSVM (Non-Linear)	70.73	84.62	74.77	83.15	86.76	66.92	57.83
RVFLAE	49.95	57.97	72.53	61.12	58.90	60.37	56.45
RVFL	61.73	60.43	77.49	64.89	72.27	68.20	55.80
SVM	56.65	67.37	75.33	68.42	69.20	65.88	55.81
TBSVM (Linear)	65.08	71.91	76.81	73.97	73.70	72.53	60.11
TBSVM (Non-Linear)	68.81	73.44	79.71	79.27	79.65	73.38	59.92
TWSVM (Linear)	58.92	63.72	76.81	68.21	68.12	66.41	58.29
TWSVM (Non-Linear)	67.79	72.27	78.10	78.16	77.83	72.73	57.94

F. Neural Network

Neural networks [10] are network of node layers comprising of an input layer, multiple hidden layers and an output layer. Each layer has multiple number of nodes and the nodes of each layer are interconnected with the other layers. Each of the nodes consists of weights which are tuned by training on the examples. The output of each of the layer is calculated through an activation function, which is then passed to the next layer. We have divided the dataset into 85% training and 15% test set for our network. The layers of our network depending upon the activation functions are Feature Input Layer $\rightarrow$ Fully Connected Layer $\rightarrow$ Batch Normalized Layer $\rightarrow$ Relu Layer $\rightarrow$ Fully Connected Layer $\rightarrow$ SoftMaxLayer $\rightarrow$ Classification Layer.

For the tuning of our parameters, we have used Adam Optimizer. It is the combination of the Stochastic Gradient Descent with momentum and the Root Mean Square Propagation and hence is quite efficient.

The network once trained, is used to make predictions on the test set.

II. Supplementary Tables

Tables S-1, S-2, S-3, S-4, S-5, S-6 are other performance metrics (AUCs, Sensitivity, Specificity, Precision, F-Measure and G-Mean) for White Matter (900 features). Tables S-7, S-8, S-9, S-10, S-11, S-12 are other performance metrics for integrated GM and WM (500 features). Tables S-13, S-14, S-15, S-16, S-17, S-18 are other performance metrics for Grey Matter (1200 features).

References

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TABLE S-2: Sensitivities of the classification models for White Matter (900 features).

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	63.27	63.56	80.56	59.99	59.88	60.84	38.35
KNN	25.35	52.64	62.98	17.20	16.09	41.32	18.92
KRR (Linear)	65.13	69.07	72.19	70.23	70.23	67.75	52.38
KRR (Non-Linear)	53.96	70.05	61.21	61.12	60.00	62.29	30.03
LSTWSVM (Linear)	68.73	67.88	82.75	70.35	68.69	74.15	58.91
LSTWSVM (Non-Linear)	73.35	73.56	70.04	73.62	80.81	77.19	65.20
MPRaF-N	76.25	68.80	82.48	63.42	57.25	65.19	67.48
MPRaF-P	60.92	58.28	65.00	65.49	59.00	61.60	32.04
MPRaF-T	54.13	56.42	67.75	47.65	49.66	30.17	39.51
Neural	48.56	60.27	78.50	61.18	58.92	57.98	46.44
pinGTSVM	61.40	63.77	66.03	74.71	71.04	62.53	56.38
RaF-LDA	51.10	55.60	63.11	52.36	53.24	56.57	25.79
RaF-PCA	57.64	60.01	67.21	58.27	52.15	48.35	33.14
RaF	55.28	55.32	66.72	66.83	58.56	62.42	35.99
RELSTSVM (Linear)	71.96	71.63	81.77	72.44	72.44	71.25	57.46
RELSTSVM (Non-Linear)	67.77	67.67	87.40	79.06	77.51	78.44	61.95
RVFLAE	42.71	52.24	66.21	58.33	58.33	55.16	56.88
RVFL	49.22	56.24	76.21	64.42	68.61	63.32	52.27
SVM	51.34	68.41	74.85	66.92	67.94	59.18	51.46
TBSVM (Linear)	72.09	72.19	70.72	74.26	72.60	72.75	57.50
TBSVM (Non-Linear)	71.34	70.08	77.46	74.00	80.23	64.91	46.54
TWSVM (Linear)	54.09	57.61	71.72	69.06	68.88	61.73	59.11
TWSVM (Non-Linear)	73.65	82.16	73.12	65.04	64.37	64.50	44.11

TABLE S-3: Specificity of classification models for White Matter (900 features).

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	72.70	71.02	86.80	77.04	78.40	74.33	64.11
KNN	82.77	78.16	86.77	95.28	93.85	81.33	72.73
KRR (Linear)	66.65	71.77	75.14	74.70	74.70	42.32	56.73
KRR (Non-Linear)	76.69	64.79	86.78	81.06	82.31	75.14	77.80
LSTWSVM (Linear)	67.19	65.39	77.44	66.78	65.42	71.14	57.96
LSTWSVM (Non-Linear)	72.38	72.41	73.68	74.09	79.13	71.69	57.39
MPRaF-N	50.90	66.62	63.59	77.95	71.38	67.33	35.25
MPRaF-P	71.52	72.47	74.20	75.33	73.88	73.63	71.42
MPRaF-T	72.35	57.46	81.33	84.62	84.42	83.85	59.66
Neural	63.53	72.25	85.31	67.48	65.89	65.39	46.66
pinGTSVM	50.17	54.22	81.57	64.38	64.49	37.67	40.19
RaF-LDA	64.58	74.08	89.40	73.36	82.52	77.85	73.69
RaF-PCA	67.44	77.42	77.01	76.79	77.74	77.33	60.94
RaF	69.17	73.04	75.82	72.35	69.12	76.42	66.77
RELSTSVM (Linear)	69.89	71.27	78.65	71.04	71.04	68.72	57.58
RELSTSVM (Non-Linear)	68.33	70.59	81.81	77.86	77.53	72.94	58.82
RVFLAE	57.19	63.70	78.85	63.91	59.46	65.58	56.02
RVFL	74.24	64.63	78.77	65.37	75.94	73.09	59.33
SVM	61.96	66.33	75.81	69.91	70.46	72.59	60.15
TBSVM (Linear)	58.07	71.63	82.91	73.69	74.80	72.31	62.71
TBSVM (Non-Linear)	66.29	76.80	81.96	84.54	79.06	81.84	73.31
TWSVM (Linear)	63.75	69.83	81.91	67.35	67.35	71.08	57.46
TWSVM (Non-Linear)	61.93	62.37	83.07	91.28	91.28	80.96	71.78

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TABLE S-4: Precision of classification models for White Matter (900 features).

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	69.45	69.61	84.71	74.13	73.58	69.92	50.08
KNN	52.83	70.18	81.75	NaN	NaN	67.98	32.95
KRR (Linear)	69.73	70.97	72.06	71.31	71.31	55.01	53.35
KRR (Non-Linear)	71.87	67.75	79.48	77.53	78.89	69.09	64.19
LSTWSVM (Linear)	59.52	60.49	71.45	64.78	63.67	61.82	54.45
LSTWSVM (Non-Linear)	63.24	68.73	79.42	76.75	75.78	67.13	52.89
MPRaF-N	63.51	68.59	67.60	75.48	69.35	66.65	50.71
MPRaF-P	68.79	68.29	69.28	74.44	70.58	72.45	52.88
MPRaF-T	68.22	NaN	75.31	74.08	79.95	72.33	50.02
Neural	56.87	68.40	82.23	63.73	60.33	63.04	44.84
pinGTSVM	57.18	56.86	75.65	68.18	66.18	49.46	47.90
RaF-LDA	59.49	70.65	86.13	68.46	76.67	71.81	NaN
RaF-PCA	64.83	72.07	74.84	71.59	71.76	66.57	44.83
RaF	64.19	70.36	72.54	70.60	67.15	74.11	50.35
RELSTSVM (Linear)	62.51	71.18	75.46	71.08	71.08	67.03	58.19
RELSTSVM (Non-Linear)	68.12	75.99	77.62	79.56	81.14	68.74	56.86
RVFLAE	43.47	58.43	74.63	60.99	58.27	61.37	57.48
RVFL	63.42	61.00	75.61	62.65	72.89	69.18	50.61
SVM	55.09	66.95	72.99	66.70	66.97	70.02	57.20
TBSVM (Linear)	65.67	70.82	79.75	71.38	71.20	71.35	59.65
TBSVM (Non-Linear)	67.36	75.31	78.52	81.40	77.62	75.26	56.96
TWSVM (Linear)	59.28	65.49	77.73	67.52	67.83	66.84	56.58
TWSVM (Non-Linear)	67.63	69.73	78.39	84.05	82.38	75.22	55.89

TABLE S-5: F-Measures for White Matter for 900 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	64.33	64.11	81.89	61.47	62.45	62.39	NaN
KNN	NaN	58.40	69.46	NaN	NaN	47.93	NaN
KRR (Linear)	65.47	68.22	71.02	68.54	68.54	57.01	51.34
KRR (Non-Linear)	58.46	66.42	68.33	65.49	65.29	64.73	37.97
LSTWSVM (Linear)	60.79	61.48	72.13	65.25	64.10	63.07	55.46
LSTWSVM (Non-Linear)	64.74	69.60	80.26	77.30	77.14	67.93	53.68
MPRaF-N	63.96	66.09	71.52	65.35	56.24	63.49	54.44
MPRaF-P	61.84	61.11	66.01	67.39	60.88	62.29	NaN
MPRaF-T	58.15	NaN	69.73	54.76	58.31	38.30	41.98
Neural	49.86	62.74	79.43	61.22	57.63	59.67	44.49
pinGTSVM	55.21	58.32	68.97	71.02	68.13	53.62	50.50
RaF-LDA	53.25	58.66	71.15	57.34	61.52	62.24	NaN
RaF-PCA	58.97	63.26	69.25	62.86	57.12	53.53	36.71
RaF	57.31	59.80	67.83	67.79	58.61	64.53	39.84
RELSTSVM (Linear)	63.63	71.80	75.85	72.19	72.19	67.87	58.88
RELSTSVM (Non-Linear)	68.82	76.79	77.95	80.03	81.63	69.32	57.58
RVFLAE	NaN	53.97	69.21	58.51	57.44	56.56	55.49
RVFL	53.80	58.03	75.00	61.45	69.95	65.02	NaN
SVM	51.72	66.28	72.76	65.28	65.84	60.93	52.46
TBSVM (Linear)	67.18	70.37	74.12	70.64	70.01	68.48	56.52
TBSVM (Non-Linear)	67.03	71.14	77.61	76.66	77.99	68.22	NaN
TWSVM (Linear)	55.35	59.41	74.02	66.80	67.04	63.04	56.64
TWSVM (Non-Linear)	68.53	72.79	75.35	72.09	70.98	67.96	NaN

TABLE S-6: G-Means for White Matter for 900 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	65.31	65.26	82.26	63.72	64.35	63.79	43.29
KNN	35.86	59.82	70.88	NaN	NaN	50.71	22.64
KRR (Linear)	66.43	69.10	71.57	69.62	69.62	59.09	52.08
KRR (Non-Linear)	60.47	67.62	69.32	67.29	67.24	65.21	41.85
LSTWSVM (Linear)	5.61	5.57	5.56	5.52	5.75	5.72	5.51
LSTWSVM (Non-Linear)	0.31	0.29	0.31	0.31	0.31	0.31	0.31
MPRaF-N	66.75	67.35	73.24	67.27	59.14	64.66	56.64
MPRaF-P	63.26	62.12	66.56	68.63	62.63	64.15	39.65
MPRaF-T	59.57	NaN	70.60	57.27	61.22	43.47	43.32
Neural	51.20	63.51	79.90	61.83	58.61	60.08	45.05
pinGTSVM	57.05	59.29	69.89	71.23	68.37	54.78	51.31
RaF-LDA	54.24	60.69	72.82	58.83	63.20	63.20	NaN
RaF-PCA	60.08	64.61	70.11	63.86	59.42	55.29	37.80
RaF	58.44	61.23	68.69	68.25	60.24	66.20	41.38
RELSTSVM (Linear)	5.50	5.38	5.40	5.36	5.44	5.42	5.54
RELSTSVM (Non-Linear)	0.35	0.33	0.33	0.35	0.34	0.34	0.34
RVFLAE	41.79	54.64	69.81	59.08	57.87	57.40	56.32
RVFL	55.01	58.32	75.45	62.47	70.34	65.63	50.69
SVM	52.45	66.97	73.33	66.03	66.63	62.71	53.38
TBSVM (Linear)	68.02	70.93	74.67	71.70	70.92	70.19	57.52
TBSVM (Non-Linear)	68.15	71.90	77.80	77.17	78.46	69.12	51.11
TWSVM (Linear)	56.00	60.44	74.37	67.54	67.69	63.65	57.23
TWSVM (Non-Linear)	69.56	74.33	75.55	73.29	72.13	68.87	48.90

TABLE S-7: AUCs for Combined Matter for 500 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	72.16	73.21	81.50	69.35	63.93	73.62	64.08
KNN	68.77	71.92	72.53	59.92	59.92	65.27	69.26
KRR (Linear)	72.22	71.00	74.07	63.64	64.98	73.74	66.33
KRR (Non-Linear)	71.89	73.68	72.18	66.68	67.73	73.22	67.17
LSTWSVM (Linear)	68.44	64.33	68.77	65.21	63.21	66.38	66.04
LSTWSVM (Non-Linear)	67.99	64.88	90.13	72.05	70.21	69.51	64.70
MPRaF-N	73.17	72.11	73.35	65.75	63.99	67.87	63.09
MPRaF-P	70.30	75.02	76.53	61.49	67.19	70.72	68.64
MPRaF-T	73.02	74.14	74.70	54.97	55.62	68.27	68.94
Neural	76.10	77.60	85.88	61.74	64.36	72.27	66.15
pinGTSVM	69.25	67.13	75.92	57.73	56.75	59.33	64.31
RaF-LDA	74.30	72.01	81.20	56.27	65.80	69.06	66.08
RaF-PCA	73.45	73.91	71.66	66.45	68.29	70.77	69.32
RaF	71.46	70.54	75.91	64.72	65.26	75.23	70.51
RELSTSVM (Linear)	76.63	75.20	73.35	64.32	64.01	74.20	63.14
RELSTSVM (Non-Linear)	74.96	72.52	76.87	77.98	78.65	79.55	64.70
RVFLAE	61.30	57.28	70.83	61.48	63.33	66.33	58.55
RVFL	72.02	71.68	75.85	71.72	66.38	68.34	60.06
SVM	75.92	70.34	71.13	61.65	65.11	66.41	60.80
TBSVM (Linear)	74.49	72.89	78.84	69.80	70.68	72.06	66.97
TBSVM (Non-Linear)	76.44	76.79	78.36	79.25	78.56	75.86	69.46
TWSVM (Linear)	71.51	67.15	77.92	69.80	69.58	70.23	66.36
TWSVM (Non-Linear)	76.21	76.32	77.90	77.37	77.30	73.90	68.82

TABLE S-8: Sensitivities for Combined Matter for 500 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	61.14	64.89	80.55	58.04	53.74	70.66	52.66
KNN	58.22	67.94	67.56	26.00	26.00	53.73	56.13
KRR (Linear)	71.35	65.93	70.08	59.34	60.77	71.70	62.32
KRR (Non-Linear)	66.47	65.38	55.99	50.60	54.95	65.70	56.52
LSTWSVM (Linear)	75.26	66.90	82.04	73.35	73.29	68.29	61.38
LSTWSVM (Non-Linear)	81.21	84.16	69.55	84.71	83.60	77.01	74.79
MPRaF-N	77.04	75.87	74.59	47.13	48.89	63.74	60.28
MPRaF-P	67.18	70.84	73.27	52.85	61.58	67.48	58.18
MPRaF-T	65.50	71.29	70.59	20.69	23.71	61.21	59.03
Neural	70.47	72.88	84.56	55.93	60.22	71.01	64.06
pinGTSVM	73.75	70.35	80.21	74.84	72.16	64.29	65.77
RaF-LDA	65.42	65.93	75.80	44.52	56.79	67.44	55.02
RaF-PCA	66.07	72.91	68.73	57.36	58.57	67.88	65.32
RaF	70.51	72.19	74.70	55.57	55.63	71.66	64.59
RELSTSVM (Linear)	71.94	71.16	84.34	73.92	77.40	70.08	72.46
RELSTSVM (Non-Linear)	77.45	80.12	82.78	80.76	80.76	73.56	74.79
RVFLAE	53.40	51.14	66.52	59.33	60.40	62.22	58.57
RVFL	66.80	62.32	75.80	64.62	60.65	67.04	57.45
SVM	70.68	63.85	69.18	52.37	65.02	65.64	59.19
TBSVM (Linear)	68.01	64.26	76.01	65.89	61.71	71.45	61.71
TBSVM (Non-Linear)	74.77	65.93	77.87	73.96	70.04	69.27	51.47
TWSVM (Linear)	66.23	61.15	75.62	65.89	63.65	69.71	65.53
TWSVM (Non-Linear)	74.96	70.86	73.35	70.21	70.21	65.58	63.67

TABLE S-9: Specificity's for Combined Matter for 500 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	83.19	81.53	82.45	80.65	74.12	76.58	75.50
KNN	79.33	75.91	77.49	93.85	93.85	76.80	82.38
KRR (Linear)	73.09	76.06	78.06	67.95	69.20	75.77	70.35
KRR (Non-Linear)	77.31	81.99	88.37	82.76	80.51	80.74	77.82
LSTWSVM (Linear)	74.46	64.95	79.68	71.10	71.17	67.50	63.50
LSTWSVM (Non-Linear)	79.17	80.32	73.93	80.24	78.04	73.64	69.01
MPRaF-N	69.30	68.34	72.10	84.38	79.08	72.00	65.90
MPRaF-P	73.42	79.20	79.79	70.12	72.80	73.96	79.10
MPRaF-T	80.55	76.99	78.81	89.25	87.53	75.34	78.86
Neural	81.73	82.32	87.21	67.54	68.51	73.54	68.25
pinGTSVM	64.76	63.91	71.63	40.62	41.34	54.36	62.84
RaF-LDA	83.19	78.10	86.60	68.02	74.80	70.67	77.14
RaF-PCA	80.83	74.91	74.58	75.54	78.01	73.66	73.32
RaF	72.41	68.90	77.12	73.87	74.88	78.80	76.43
RELSTSVM (Linear)	70.61	69.02	82.85	70.41	72.06	69.71	66.21
RELSTSVM (Non-Linear)	74.80	78.27	82.67	78.81	79.37	74.30	69.01
RVFLAE	69.20	63.42	75.13	63.63	66.25	70.43	58.52
RVFL	77.24	81.03	75.90	78.83	72.12	69.63	62.67
SVM	81.17	76.83	73.09	70.94	65.20	67.19	62.42
TBSVM (Linear)	80.96	81.52	81.66	73.71	79.65	72.67	72.22
TBSVM (Non-Linear)	78.12	87.66	78.85	84.54	87.08	82.45	87.46
TWSVM (Linear)	76.78	73.16	80.23	73.71	75.51	70.76	67.18
TWSVM (Non-Linear)	77.45	81.79	82.46	84.54	84.40	82.21	73.98

TABLE S-10: Precisions for Combined Matter for 500 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	75.62	75.06	81.49	75.64	70.40	75.96	65.13
KNN	74.84	71.14	77.50	75.83	75.83	69.92	75.78
KRR (Linear)	69.43	72.86	76.24	64.59	66.25	72.92	63.96
KRR (Non-Linear)	73.21	79.03	86.25	77.51	75.37	78.31	71.71
LSTWSVM (Linear)	69.00	63.07	72.29	64.18	62.74	65.72	63.80
LSTWSVM (Non-Linear)	70.68	69.05	80.06	74.73	72.87	69.52	64.72
MPRaF-N	67.58	68.98	70.85	75.31	74.68	69.81	62.92
MPRaF-P	71.45	77.73	77.59	64.83	71.02	71.94	76.78
MPRaF-T	74.83	74.04	77.42	NaN	NaN	70.17	75.12
Neural	80.20	80.61	87.24	63.92	63.95	74.52	65.20
pinGTSVM	66.27	64.56	72.88	55.76	53.73	58.57	61.69
RaF-LDA	76.31	74.96	84.23	60.50	72.53	67.73	72.27
RaF-PCA	75.44	75.47	72.06	70.89	72.67	69.89	69.25
RaF	69.23	69.02	76.00	68.88	69.63	75.95	76.56
RELSTSVM (Linear)	72.63	71.33	76.85	63.32	63.82	70.77	63.37
RELSTSVM (Non-Linear)	73.92	73.71	78.88	77.60	77.72	75.82	64.72
RVFLAE	66.69	58.72	72.63	61.13	63.67	68.33	53.98
RVFL	74.00	76.77	74.33	73.37	65.81	69.51	58.26
SVM	77.53	72.47	71.74	63.19	63.17	63.40	59.42
TBSVM (Linear)	74.73	75.41	81.32	71.95	74.37	70.58	66.27
TBSVM (Non-Linear)	75.90	84.48	79.25	81.45	82.14	78.49	83.50
TWSVM (Linear)	71.08	67.09	80.73	71.95	73.40	70.25	64.05
TWSVM (Non-Linear)	74.80	79.37	83.84	79.78	79.59	77.57	69.64

TABLE S-11: F-Measures for Combined Matter for 500 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	66.34	68.04	80.07	62.25	56.58	71.36	55.72
KNN	64.40	67.92	69.98	NaN	NaN	58.93	61.68
KRR (Linear)	69.55	67.96	71.66	59.90	61.44	70.89	61.19
KRR (Non-Linear)	68.76	69.24	65.33	58.08	60.13	69.29	61.39
LSTWSVM (Linear)	70.20	63.84	73.25	66.09	64.82	66.32	64.28
LSTWSVM (Non-Linear)	72.08	70.76	81.03	75.43	73.49	70.54	65.75
MPRaF-N	70.78	70.60	71.45	53.91	55.92	65.11	59.20
MPRaF-P	68.34	72.75	73.48	56.90	63.14	67.54	62.73
MPRaF-T	68.77	71.40	72.41	NaN	NaN	64.09	63.23
Neural	73.34	74.86	85.18	57.01	60.31	70.10	63.85
pinGTSVM	68.20	66.16	75.04	63.13	61.03	59.21	62.01
RaF-LDA	69.06	68.77	78.27	47.85	59.60	66.50	58.34
RaF-PCA	69.84	72.78	69.43	61.02	63.47	66.49	65.46
RaF	68.91	68.87	73.43	59.07	60.50	72.37	66.94
RELSTSVM (Linear)	73.12	71.72	77.47	65.27	65.81	71.36	63.99
RELSTSVM (Non-Linear)	74.39	74.54	79.32	77.99	78.35	76.37	65.75
RVFLAE	57.65	52.59	67.52	58.46	60.51	63.50	NaN
RVFL	69.03	67.06	74.42	66.12	60.12	66.85	56.93
SVM	72.57	66.54	68.85	55.06	62.40	63.17	58.17
TBSVM (Linear)	70.14	67.61	77.60	65.61	64.10	69.67	62.57
TBSVM (Non-Linear)	73.79	71.56	77.72	76.87	74.78	71.58	59.38
TWSVM (Linear)	67.86	62.87	77.19	65.61	64.50	68.37	63.74
TWSVM (Non-Linear)	73.92	73.25	76.02	73.82	73.73	69.35	64.48

TABLE S-12: G-Means for Combined Matter for 500 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	67.34	68.97	80.54	64.04	58.81	72.32	57.22
KNN	65.44	68.72	71.19	43.47	43.47	60.29	63.71
KRR (Linear)	69.97	68.66	72.39	60.90	62.44	71.59	62.10
KRR (Non-Linear)	69.29	70.67	68.05	60.54	62.13	70.60	62.71
LSTWSVM (Linear)	7.19	7.06	7.00	7.08	7.05	7.15	7.77
LSTWSVM (Non-Linear)	0.47	0.47	0.49	0.48	0.48	0.48	0.48
MPRaF-N	71.53	71.50	72.08	56.93	58.63	65.93	60.36
MPRaF-P	68.82	73.51	74.44	57.84	64.53	68.60	64.83
MPRaF-T	69.46	72.00	73.20	NaN	NaN	64.88	65.06
Neural	74.31	75.78	85.54	58.43	61.17	71.37	64.24
pinGTSVM	69.09	66.80	75.79	64.19	61.98	60.27	62.86
RaF-LDA	69.93	69.59	79.12	49.95	61.98	67.03	60.58
RaF-PCA	70.29	73.48	69.91	62.54	64.51	67.66	66.34
RaF	69.39	69.73	74.37	60.45	61.53	73.08	68.68
RELSTSVM (Linear)	6.81	6.82	6.83	6.78	6.76	6.81	7.83
RELSTSVM (Non-Linear)	0.48	0.51	0.49	0.49	0.49	0.49	0.49
RVFLAE	58.81	53.72	68.52	59.33	61.26	64.37	55.20
RVFL	69.70	68.27	74.74	67.51	61.61	67.55	57.39
SVM	73.32	67.33	69.65	56.33	63.23	63.83	58.73
TBSVM (Linear)	70.75	68.68	78.13	67.20	65.95	70.33	63.25
TBSVM (Non-Linear)	74.55	73.29	78.14	77.28	75.42	72.71	63.02
TWSVM (Linear)	68.25	63.48	77.68	67.20	66.37	69.17	64.26
TWSVM (Non-Linear)	74.39	74.16	77.27	74.40	74.30	70.44	65.55

TABLE S-13: AUCs for Grey Matter for 1200 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	63.57	60.49	76.64	71.23	74.30	70.01	69.46
KNN	59.69	58.61	73.18	63.71	65.26	68.16	66.20
KRR (Linear)	60.88	58.58	76.71	71.00	70.38	67.07	71.53
KRR (Non-Linear)	67.94	68.73	76.21	74.02	73.18	70.22	68.02
LSTWSVM (Linear)	58.44	62.63	75.85	66.52	63.27	65.87	65.50
LSTWSVM (Non-Linear)	55.74	54.45	73.97	81.13	81.55	66.29	70.75
MPRaF-N	62.84	63.68	73.53	70.02	75.02	66.76	73.31
MPRaF-P	64.85	63.73	69.86	72.28	71.48	68.73	70.09
MPRaF-T	67.25	65.25	75.63	69.30	69.36	64.28	72.80
Neural	62.17	60.91	73.95	62.13	65.98	61.62	66.88
pinGTSVM	58.55	55.26	70.95	68.45	70.85	63.23	68.67
RaF-LDA	65.27	56.57	78.28	69.44	64.79	67.44	66.61
RaF-PCA	66.48	57.90	77.62	69.02	74.14	67.57	61.75
RaF	65.94	63.39	71.93	71.34	71.25	67.53	68.16
RELSTSVM (Linear)	53.90	57.92	76.41	68.37	67.04	72.60	67.72
RELSTSVM (Non-Linear)	58.24	59.73	72.48	86.20	86.45	65.88	70.61
RVFLAE	55.24	53.33	70.27	58.89	62.45	59.08	65.41
RVFL	61.64	64.68	71.14	72.08	67.09	67.04	66.40
SVM	54.87	60.42	74.90	73.29	75.38	61.09	75.05
TBSVM (Linear)	63.44	64.76	79.26	71.93	73.88	69.20	73.29
TBSVM (Non-Linear)	70.55	69.18	77.47	82.89	83.30	70.93	77.88
TWSVM (Linear)	59.68	59.19	73.84	71.93	67.43	67.45	68.39
TWSVM (Non-Linear)	66.19	66.75	77.55	82.76	83.30	71.66	77.88

TABLE S-14: Sensitivities for Grey Matter for 1200 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	54.57	55.64	72.07	66.58	69.92	63.90	60.97
KNN	46.15	46.00	66.23	34.75	37.84	59.15	37.56
KRR (Linear)	54.17	53.58	72.31	59.50	59.92	61.63	67.98
KRR (Non-Linear)	45.77	51.84	60.72	51.81	52.81	64.54	54.78
LSTWSVM (Linear)	60.56	53.87	74.67	74.08	76.50	70.01	73.63
LSTWSVM (Non-Linear)	73.31	75.38	82.35	80.67	83.46	75.95	81.84
MPRaF-N	62.53	54.53	73.58	58.56	65.58	59.18	67.86
MPRaF-P	54.90	56.56	66.52	67.19	62.08	65.07	60.62
MPRaF-T	55.46	59.91	67.25	55.56	53.38	52.21	63.33
Neural	59.89	61.77	71.55	62.11	65.88	63.29	61.83
pinGTSVM	57.42	56.69	70.28	79.02	82.95	72.44	80.06
RaF-LDA	54.70	49.90	72.98	64.33	63.84	60.62	56.18
RaF-PCA	66.02	54.49	74.26	67.53	76.08	63.46	56.39
RaF	56.63	51.54	71.80	65.96	61.84	63.77	63.75
RELSTSVM (Linear)	75.90	70.59	80.12	79.09	79.63	66.90	80.10
RELSTSVM (Non-Linear)	77.66	77.83	83.29	79.43	81.54	73.94	83.95
RVFLAE	54.48	48.60	63.29	57.81	59.99	57.09	56.64
RVFL	58.81	64.29	63.60	68.02	62.72	56.99	62.96
SVM	49.19	53.45	69.81	62.94	66.58	66.79	69.44
TBSVM (Linear)	51.40	61.98	76.41	71.20	63.01	67.63	64.94
TBSVM (Non-Linear)	50.36	51.79	79.26	85.48	82.80	64.97	68.61
TWSVM (Linear)	54.52	55.02	67.56	71.20	65.95	72.65	68.87
TWSVM (Non-Linear)	54.21	38.83	76.40	83.98	82.80	68.79	68.61

TABLE S-15: Specificity's for Grey Matter for 1200 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	72.56	65.33	81.21	75.88	78.69	76.12	77.95
KNN	73.24	71.21	80.13	92.68	92.68	77.17	94.83
KRR (Linear)	67.58	63.59	81.12	82.50	80.83	72.52	75.08
KRR (Non-Linear)	90.11	85.61	91.70	96.22	93.56	75.89	81.25
LSTWSVM (Linear)	58.87	56.62	75.17	72.00	73.86	66.39	72.68
LSTWSVM (Non-Linear)	65.85	70.20	80.73	80.21	83.99	77.89	79.83
MPRaF-N	63.15	72.82	73.48	81.48	84.46	74.34	78.75
MPRaF-P	74.81	70.89	73.20	77.37	80.89	72.39	79.57
MPRaF-T	79.03	70.60	84.02	83.03	85.33	76.34	82.27
Neural	64.46	60.05	76.34	62.15	66.08	59.94	71.94
pinGTSVM	59.67	53.84	71.62	57.88	58.74	54.02	57.27
RaF-LDA	75.83	63.24	83.58	74.55	65.74	74.25	77.03
RaF-PCA	66.95	61.31	80.98	70.50	72.20	71.69	67.12
RaF	75.25	75.25	72.05	76.71	80.67	71.30	72.58
RELSTSVM (Linear)	67.19	63.38	77.97	74.59	75.28	69.31	79.17
RELSTSVM (Non-Linear)	74.87	71.44	82.33	79.69	82.02	75.74	83.14
RVFLAE	56.01	58.05	77.25	59.98	64.91	61.08	74.19
RVFL	64.46	65.08	78.69	76.13	71.45	77.09	69.85
SVM	60.55	67.38	80.00	83.63	84.18	55.38	80.66
TBSVM (Linear)	75.49	67.54	82.12	72.66	84.74	70.77	81.63
TBSVM (Non-Linear)	90.75	86.58	75.69	80.29	83.79	76.89	87.15
TWSVM (Linear)	64.84	63.35	80.13	72.66	68.91	62.25	67.91
TWSVM (Non-Linear)	78.17	94.67	78.70	81.54	83.79	74.52	87.15

TABLE S-16: Precisions for Grey Matter for 1200 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	68.39	62.74	77.72	72.17	76.19	72.81	74.44
KNN	70.13	66.25	77.86	83.83	83.50	69.95	88.00
KRR (Linear)	60.49	57.71	78.17	75.13	74.43	68.59	73.82
KRR (Non-Linear)	84.74	81.06	89.31	92.50	88.33	73.06	74.64
LSTWSVM (Linear)	56.76	57.24	74.15	67.33	65.93	NaN	66.24
LSTWSVM (Non-Linear)	59.57	59.09	76.17	79.34	80.65	67.14	73.47
MPRaF-N	63.22	68.62	74.17	76.95	84.38	74.10	74.70
MPRaF-P	69.63	66.87	74.38	76.87	79.38	71.84	73.93
MPRaF-T	76.52	68.12	83.14	79.22	84.13	70.22	78.05
Neural	63.63	60.39	75.83	60.07	67.48	59.73	69.13
pinGTSVM	58.06	54.13	71.21	63.91	65.47	60.11	65.58
RaF-LDA	71.08	62.04	81.30	75.15	65.41	68.06	72.95
RaF-PCA	67.06	58.78	79.53	69.92	72.59	65.48	64.94
RaF	69.84	68.88	72.76	75.18	77.33	68.42	69.46
RELSTSVM (Linear)	58.22	59.20	75.82	69.33	69.85	68.70	69.98
RELSTSVM (Non-Linear)	62.94	63.53	75.74	81.38	82.74	67.28	74.78
RVFLAE	55.19	56.17	74.26	57.52	62.43	56.67	68.43
RVFL	61.25	65.62	74.15	75.07	68.61	71.23	68.50
SVM	54.29	61.99	76.53	79.13	79.36	59.15	78.75
TBSVM (Linear)	66.49	63.43	80.25	71.45	77.54	69.51	79.71
TBSVM (Non-Linear)	88.17	84.69	77.06	80.80	84.21	73.06	84.50
TWSVM (Linear)	61.44	59.94	78.50	71.45	68.70	65.67	67.22
TWSVM (Non-Linear)	73.55	92.50	79.67	81.49	84.21	77.97	84.50

TABLE S-17: F-Measures for Grey Matter for 1200 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	57.93	57.06	73.10	68.43	71.01	66.81	63.71
KNN	52.62	52.10	70.19	46.47	48.91	61.96	50.05
KRR (Linear)	55.32	53.49	73.79	64.42	64.66	62.90	67.68
KRR (Non-Linear)	58.07	61.82	69.89	65.41	65.34	66.59	61.71
LSTWSVM (Linear)	57.67	58.37	74.82	68.28	67.23	65.31	67.61
LSTWSVM (Non-Linear)	60.18	60.61	76.75	80.00	81.69	69.51	74.37
MPRaF-N	60.65	58.57	71.17	64.23	70.69	62.07	68.81
MPRaF-P	58.54	58.62	67.40	69.27	67.50	65.71	64.66
MPRaF-T	61.67	61.69	71.52	63.46	63.49	57.53	67.67
Neural	60.27	59.63	72.62	59.09	63.52	59.68	63.90
pinGTSVM	55.75	53.07	70.21	69.09	72.04	63.94	69.18
RaF-LDA	59.94	51.38	75.62	65.97	63.28	62.77	60.42
RaF-PCA	64.32	55.12	74.92	66.93	72.67	63.29	58.01
RaF	59.46	55.91	69.33	68.31	67.29	64.62	65.85
RELSTSVM (Linear)	59.36	59.92	76.50	70.39	70.50	69.81	71.65
RELSTSVM (Non-Linear)	64.66	64.53	76.56	82.15	83.48	68.97	75.81
RVFLAE	52.98	50.30	66.02	55.25	58.63	NaN	59.58
RVFL	59.24	64.13	67.25	69.60	63.64	61.61	63.13
SVM	50.86	56.61	71.76	67.44	70.09	60.93	71.42
TBSVM (Linear)	56.71	60.01	77.44	70.21	68.12	66.42	68.45
TBSVM (Non-Linear)	61.48	61.32	77.37	81.60	82.11	66.94	73.70
TWSVM (Linear)	56.00	56.19	71.48	70.21	65.76	66.83	65.19
TWSVM (Non-Linear)	61.12	53.27	76.69	81.35	82.11	68.34	73.70

TABLE S-18: G-Means for Grey Matter for 1200 features.

Methods	T-Test	ROC	Wilcoxon	Entropy	Bhattacharyya	MRMR	NCA
Het-RaF	59.63	58.10	73.98	68.90	72.02	67.57	65.64
KNN	55.02	53.96	71.11	52.11	54.07	63.22	55.86
KRR (Linear)	56.29	54.53	74.50	65.84	65.89	63.98	69.24
KRR (Non-Linear)	61.50	64.04	72.36	68.63	67.88	67.68	63.17
LSTWSVM (Linear)	10.42	10.49	10.41	10.56	10.49	10.56	10.55
LSTWSVM (Non-Linear)	0.54	0.55	0.53	0.55	0.56	0.55	0.54
MPRaF-N	61.72	60.03	72.50	65.95	72.75	64.08	70.02
MPRaF-P	60.30	60.12	68.86	70.61	69.08	67.01	65.94
MPRaF-T	63.74	62.81	73.28	65.38	66.02	59.31	69.15
Neural	61.01	60.35	73.15	60.08	65.05	60.58	64.68
pinGTSVM	56.71	54.19	70.48	70.25	73.10	65.08	70.95
RaF-LDA	61.38	53.38	76.37	67.77	63.95	63.55	62.40
RaF-PCA	65.39	55.86	75.89	67.82	73.48	63.87	59.25
RaF	61.24	57.93	70.78	69.42	68.41	65.34	66.22
RELSTSVM (Linear)	11.61	9.94	10.12	10.06	10.14	10.09	10.23
RELSTSVM (Non-Linear)	0.58	0.57	0.56	0.56	0.55	0.57	0.56
RVFLAE	53.88	51.31	67.38	56.43	59.88	56.21	61.01
RVFL	59.63	64.54	68.05	70.56	64.64	62.82	64.41
SVM	51.29	57.16	72.46	69.11	71.48	61.93	72.71
TBSVM (Linear)	57.80	61.31	77.88	70.77	69.18	67.48	70.33
TBSVM (Non-Linear)	64.98	64.41	77.76	82.36	82.80	67.94	75.10
TWSVM (Linear)	56.97	56.83	72.24	70.77	66.54	67.97	66.59
TWSVM (Non-Linear)	62.43	58.90	77.36	82.03	82.80	70.75	75.10