Volume of tissue activated and patient characteristics predict deep brain stimulation outcomes in Parkinson's disease

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Introduction

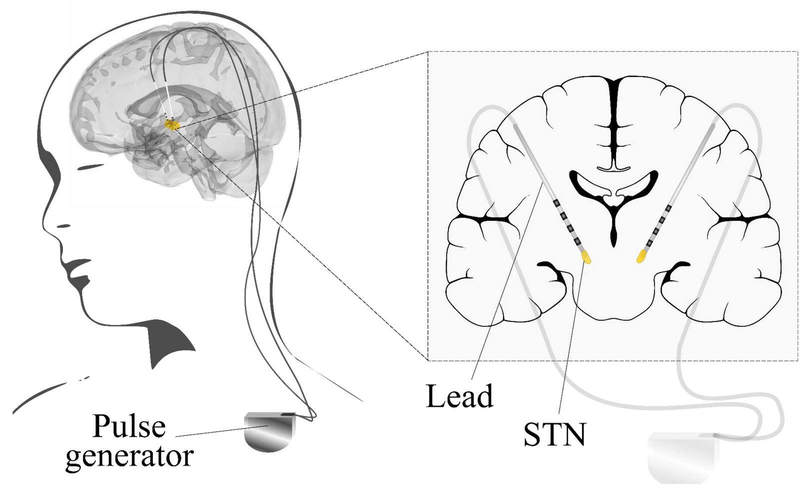

Figure 1 STN-DBS electrode implantation.

- Deep brain stimulation (DBS) of the subthalamic nucleus (STN) is an effective treatment for motor symptoms in Parkinson's disease (PD) (Fig. 1).
- Studies have shown that the clinical effects of STN-DBS depend on the shape, size, and location of the volume of tissue activated (VTA) [1, 2], while others have reported no significant correlation between VTA position and postoperative motor outcomes [3].
- This study aimed to predict STN-DBS-induced PD-symptom differences using the VTA of the active electrodes and patient-specific characteristics.

Methods

- Preoperative T1- and T2-weigthed and postoperative T1-weighted images were obtained from 96 PD patients with bilateral STN-DBS. VTAs were estimated from the active electrodes using the Lead-DBS pipeline [4], incorporating coregistration, spatial normalization, brainshift correction, electrode localization, and VTA simulation. Clinical outcomes were measured during STN-DBS ON and OFF states using the Movement Disorder Society Unified Parkinson's Disease Rating Scale part 3 (MDS UPDRS-III).
- To predict the improvements of the symptoms due to stimulation, multiple regression models were employed including Linear Regression (LR), Support Vector Regression (SVR), Decision Tree (DT), Random Forest (RF), Gradient Boosting (GB), and K-Nearest Neighbours (KNN).
- Predictors were VTA characteristics including size (total, left, right), center of gravity (COG) (Fig. 2), mean, and min coordinates, as well as clinical features of age, disease duration, and sex.
- Feature selection based on univariate statistical tests was incorporated to identify the most predictive variables. The models were evaluated using Leave-One-Out Cross-Validation with mean squared error (MSE), R2, and Pearson correlation (R) between predicted and true values.

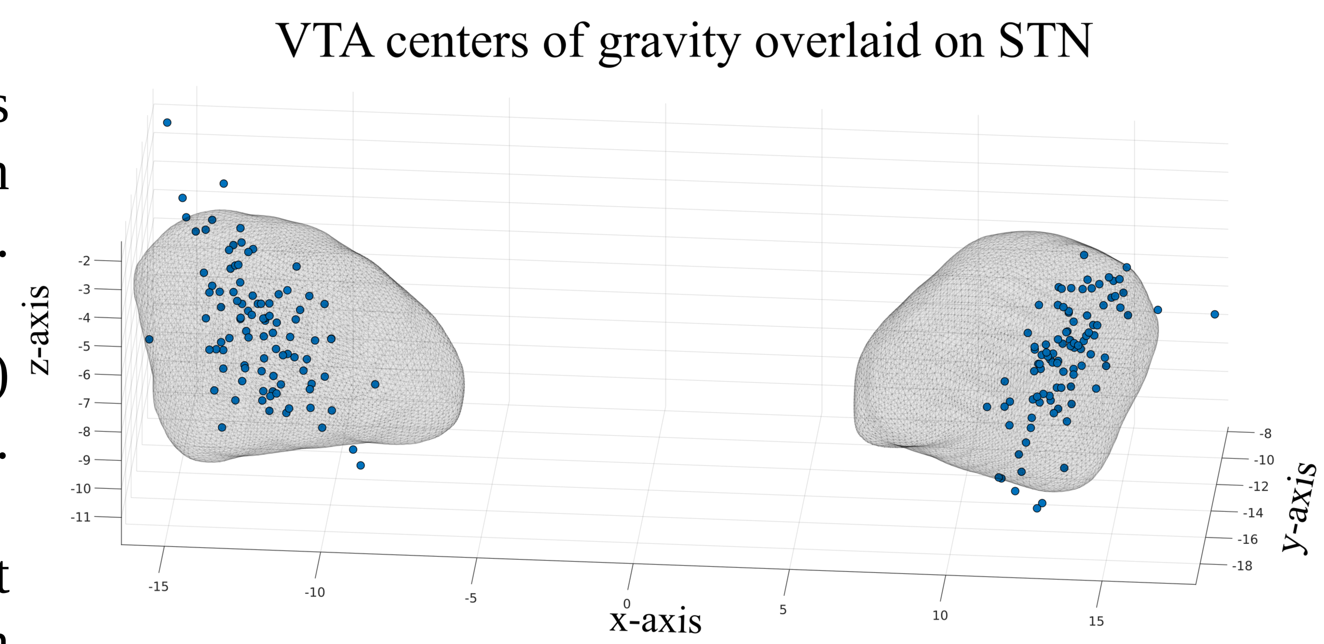

Figure 2 Scatter plot of VTA centers of gravity overlaid on STN.

Results

- GB illustrated the highest performance achieving MSE=42.44, R2=0.24, R=0.53, p<0.001 with k=13 features. The features included age, disease duration, and VTA size, coordinates of the COG, and their mean across both hemispheres. Interestingly, the coordinates of the left VTA COG had a greater influence on the predictions compared to the right, while the VTA size was chosen across all algorithms and iterations.
- LR and RF achieved almost equally by using fewer features, k=5 and k=11 respectively. Interestingly, SVR required only the total size of VTA for acquiring a comparable high performance (MSE=47.46, R2=0.15). KNN and DT were less effective with higher MSE explaining less variability of the data. The performance of the top performing models based on R2 is shown in Fig. 3 and their feature importance in Fig. 4.

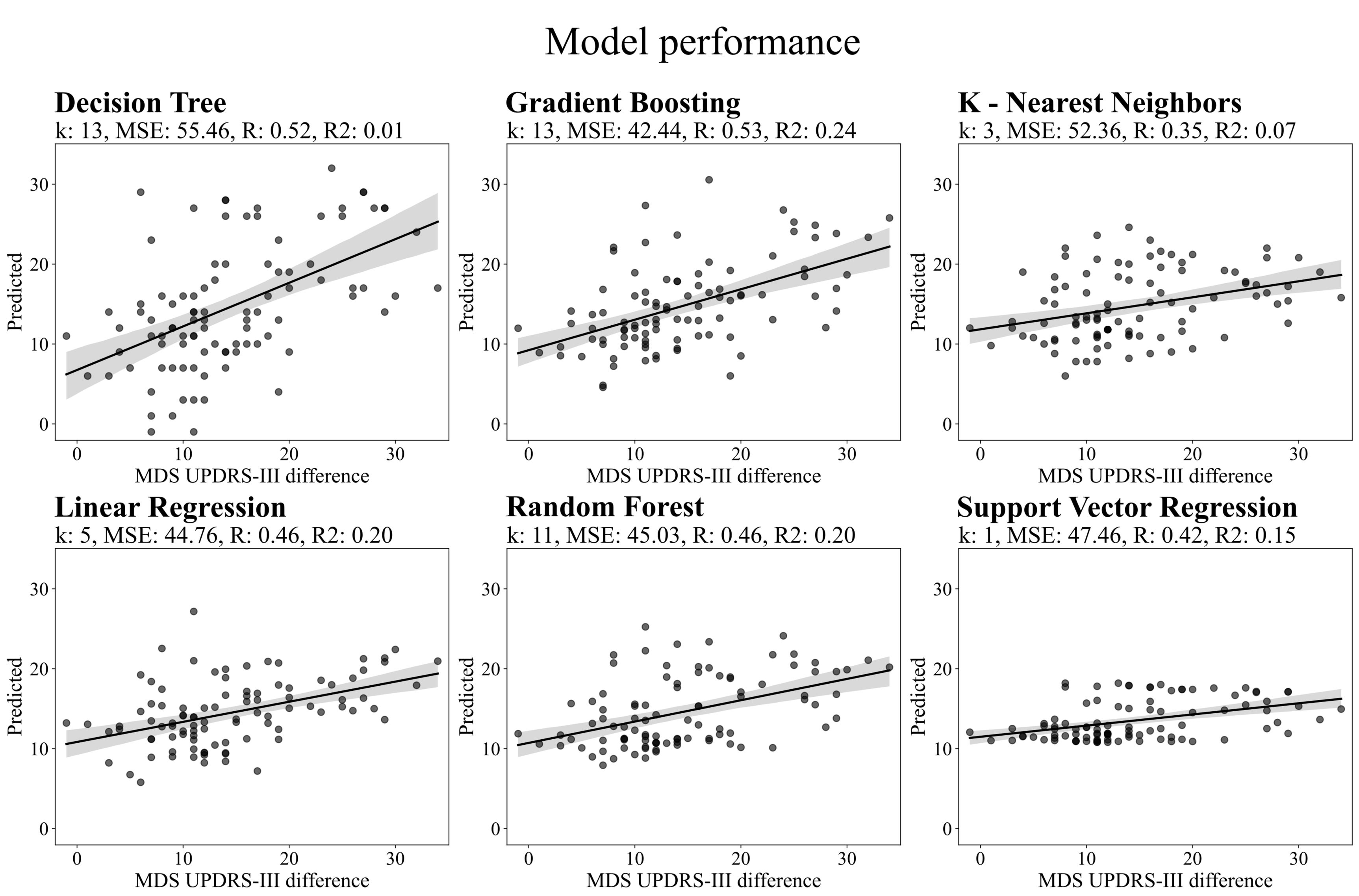

Figure 3 Model performance of the MDS UPDRS-III difference prediction. Evaluation metrics are shown above subplots including the number of selected features (k), mean squared error (MSE), Pearson correlation (R), and coefficient of determination (R2).

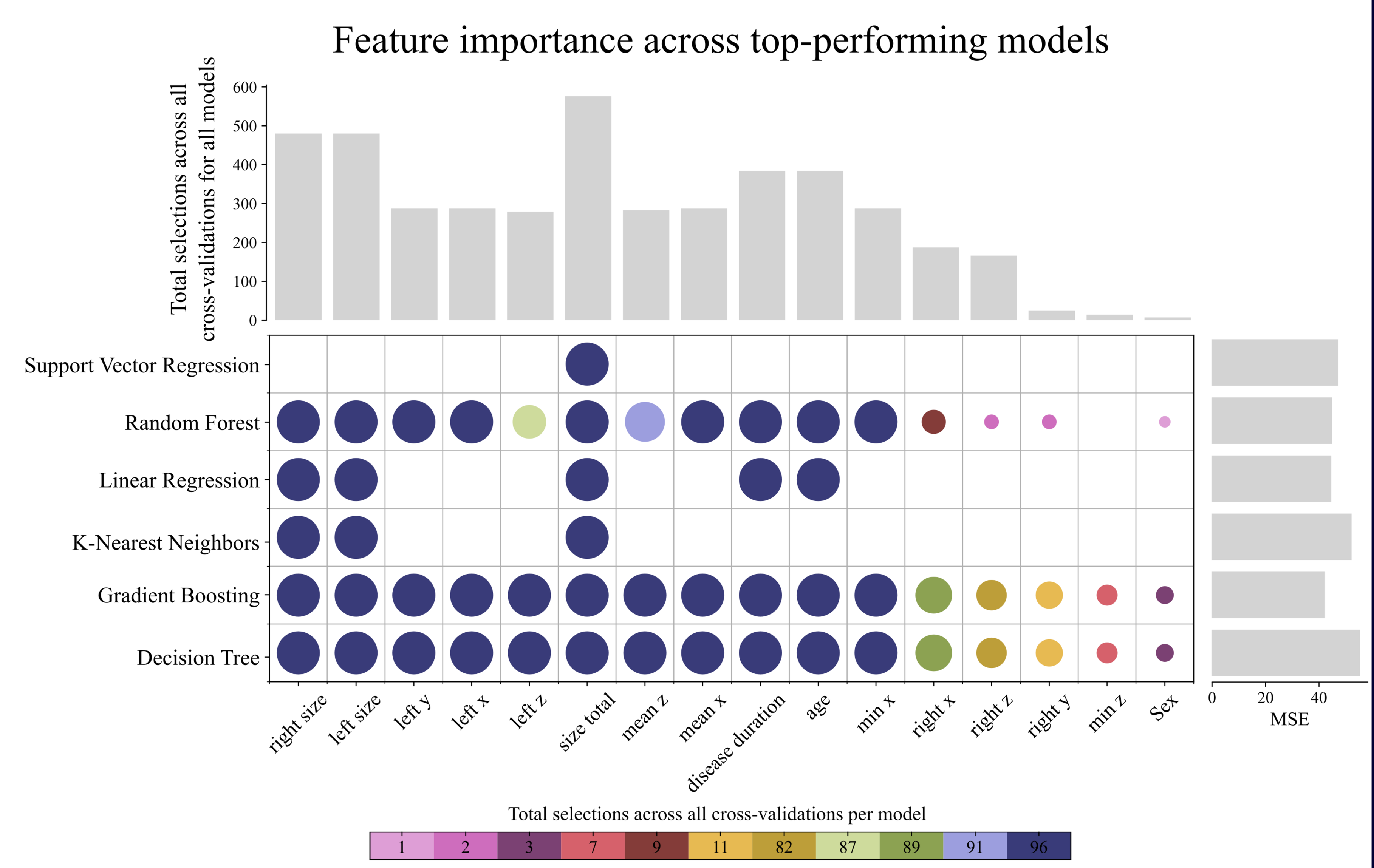

Figure 4 Feature importance of the top-performing models. The heatmap shows the number of features used with the size of the circles to be proportional to the total selection of each feature across all cross-validations. Color bar maps the times each feature was used. Right side bar chart shows the MSE and top bar chart presents the total selections of each feature across all models and cross-validations.

Conclusion

- GB, LR, and RF had the highest performance on the prediction.
- VTA COG coordinates were important predictors of clinical outcomes in STN-DBS, supporting the finding of [2].
- However, further investigation is needed to determine how these spatial properties influence the clinical outcomes.

References

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