

Searchlight optimization using representational similarity analysis for subject-level voxel selection in emotional state decoding

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Introduction

Identifying informative voxels is a critical step in multivariate fMRI analyses, particularly in studies involving multiple related mental states. Existing voxel selection approaches often rely on univariate activation criteria or classifier-based performance metrics, which may not adequately capture the representational structure underlying complex cognitive or affective processes. Representational similarity analysis (RSA) provides a flexible framework for evaluating multivoxel representations, but practical implementation requires several user-defined hyperparameters whose effects remain poorly understood. The present study introduces a systematic searchlight optimization framework that combines RSA-based voxel selection with data-driven hyperparameter optimization. We evaluated the performance of the RSA-based approach, examined the influence of key hyperparameters, tested whether optimal configurations identified from a small pilot sample generalize to a larger independent dataset, and compared the RSA-based approach with a classifier-based voxel selection approach.

Methods

Functional MRI data were collected during an emotion imagery task involving four affective states. A pilot dataset (N = 6) and an independent main dataset (N = 27) were analyzed separately. The proposed framework combined univariate preselection with RSA-based searchlight refinement to identify voxels whose local representational geometry matched predefined emotion model RDMs. Hyperparameter effects were evaluated using linear mixed-effects models across 6,480 parameter combinations. Bayesian optimization was then applied to identify high-performing configurations from the pilot dataset. Generalizability was assessed by applying optimized configurations directly to the independent main dataset. Performance was evaluated using representational similarity measures and compared with a classifier-based voxel selection approach.

Results

Several hyperparameters showed robust and interpretable effects on voxel selection performance across target models. Bayesian optimization consistently identified configurations located near the global optimum of the full grid-search landscape while requiring substantially fewer evaluations. Hyperparameter configurations optimized on the pilot dataset generalized successfully to the independent main dataset, showing significant correspondence in performance across samples. Compared with univariate selection alone, the RSA-based approach produced stronger alignment between empirical and target representational structures. Relative to classifier-based voxel selection, the RSA-based approach better preserved representational geometry while maintaining comparable discriminative performance.

Conclusions

These findings demonstrate the feasibility of combining RSA-based voxel selection with Bayesian optimization to create an efficient and practical searchlight optimization framework. The results further suggest that robust hyperparameter configurations can be identified from limited pilot data and transferred to larger datasets. Beyond improving voxel selection, the framework provides a systematic approach for optimizing representational analyses in multi-condition fMRI studies and may facilitate future applications in neurofeedback and other real-time neuroimaging paradigms.