Classification of task-unrelated thoughts based on single-trial fMRI data

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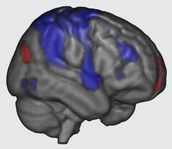
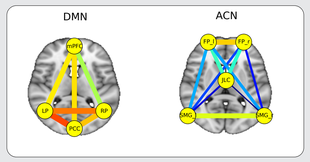
Introduction

During episodes of rest, a network of specific brain regions known as the default-mode network (DMN) is activated [1]. This network is also related to mind-wandering (task-unrelated thoughts, TUT) as measured by introspective thought-probes. Using a multivariate pattern analysis (MVPA) approach using data from fMRI and eyetracking, we classify trials in a stop-signal paradigm into on-task or TUT trials. By applying a cognitive model [2] to the behaviour as predicted by the classifier, we investigate latent cognitive processes underlying mind-wandering.

fMRI features

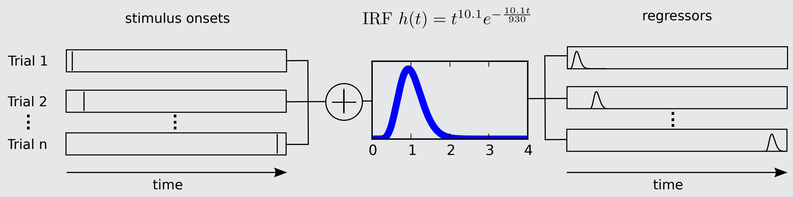




- calculate residuals $\rho_i = y_i - \sum_i \beta_i x_i$ using fcMRI GLM (task, motion, blinkrate, WM, CSF regressors)
- calculate voxel-pairwise correlations $corr(\rho_i, \rho_j)$ using a seed in the posterior cingulate cortex
- choose 5% most (anti-)correlated voxels to extract DMN and anti-correlated (task-positive) network (ACN; [4])
- project ROI (peak voxels + 3x3x3 cube) into individual space and extract mean activity across voxels per subject
- sliding-window correlation $corr_w(\rho_i(t), \rho_j(t))$ for $t \in \{k, \ldots, k+w\}$ between all ROIs

Pupillometric features

- baseline-pupil diameter before probe (mean over $[-1000, 0]$ ms)
- pupillometric response extracted using GLM:



References

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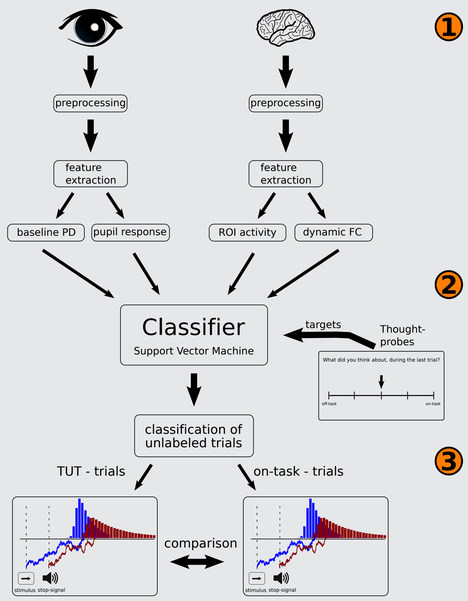
[2] Logan GD, Van Zandt T, Verbruggen F, Wagenmakers EJ (in press) On the ability to inhibit thought and action: General and special theories of an act of control. Psych Rev.

[3] Schölkopf B, Smola AJ (2002) Learning with Kernels. MIT Press, Cambridge, MA.

[4] Fox MD, Snyder AZ, Vincent JL, Corbetta M, Van Essen DC, Raichle ME (2005) The human brain is intrinsically organized into dynamic, anticorrelated functional networks. Proc Natl Acad Sci U S 102:9673-9678.

Approach



① Feature Extraction

- data from different modalities:
  - brain data (fMRI)
  - eye-tracker (pupil diameter)
- extract theoretically relevant features:
  - ROI activity, functional connectivity
  - baseline, and evoked pupil diameter

② Classification

- radial basis-function SVM:
  - global optimization of parameters
  - feature selection
- classification of unlabeled trials:
  - analysis of periods of TUT
  - analysis of feature importance

③ Cognitive Model

- Stop-Signal Drift-Diffusion Model:
  - analyse cognitive processes underlying mind-wandering

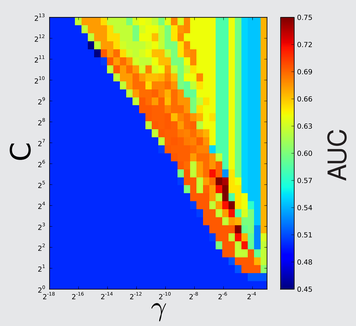
Experimental Setup

- N=20 subjects in an 2-AFC, auditory Stop-Signal task
- simultaneous fMRI and eyetracking

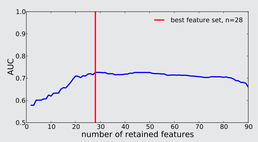
Classifier Setup

- Support-vector machine with gaussian radial basis functions [3]
- binarize extreme-valued thought-probes to get labeled data
- optimize RBF-SVM parameters (C, γ) using AUC criterion
- Cross-Subject Crossvalidation Accuracy: **79.5%**
- label all trials using this classifier $\rightarrow$ extract statistics

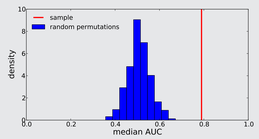
Parameter Optimization



Feature Selection

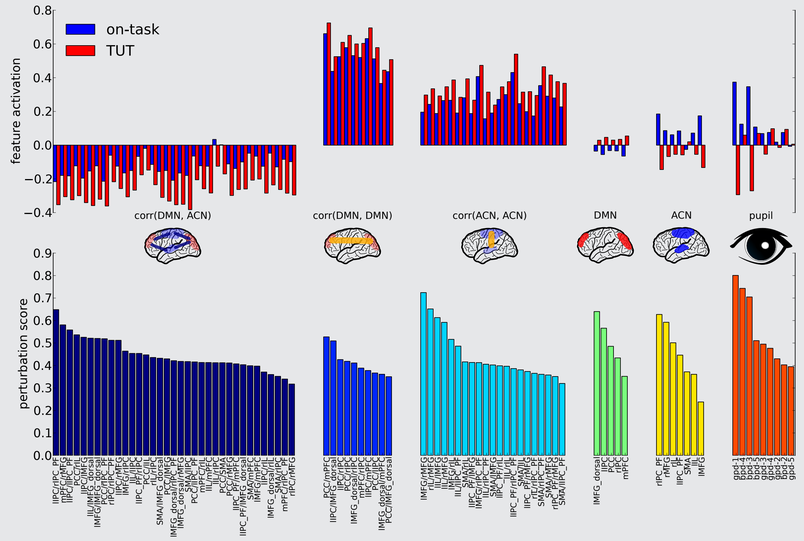


Random Permutation Test

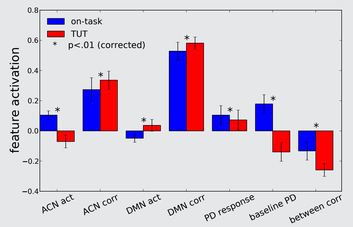


Classification Results

Feature-activation by Noise-Perturbation Sensitivity in TUT vs. on-task trials

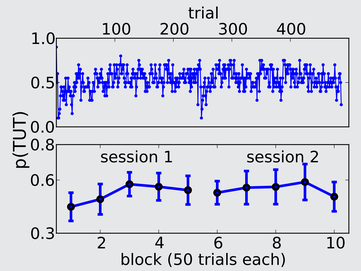


Classifier Extracts Theoretical Plausible Discrimination

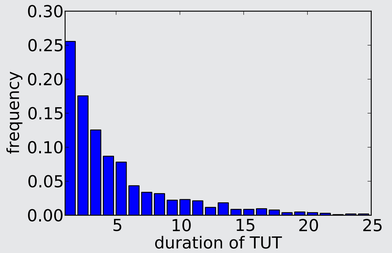


- ACN more active in on-task trials
- DMN more active in TUT trials
- reduced pupillary response in TUT trials

Analysis of frequency of TUT over trials



- TUTs increase with time



- TUTs are mainly short

Cognitive Model (work in progress)

Stop-Signal Diffusion Model [2]

- include classifier uncertainty: $p(t|\theta) = p_{acc} p_{TUT}(t) + (1 - p_{acc}) p_{on}(t)$
- Bayesian Parameter estimation