# Support Vector Machine Classification of Spontaneous Cognition Using Whole-Brain Resting-State Functional Connectivity

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**Target audience**
fMRI Researcher, Cognitive Neuroscientists, Psychologists and Psychiatrists

**Purpose**
Resting-state fMRI (rs-fMRI) is a powerful method of identifying spatially distinct areas of the brain that demonstrate synchronous BOLD fluctuations at rest [1]. Although it has been suggested that the resting-state functional connectivity (RSFC) can be detected reliably across multiple scan sessions, there exists considerably variability in the RSFC measures between healthy participants [2]. During rs-fMRI scan, mental activities such as "inner language" (e.g., imagining/recalling words, phrases, or sentences without overt production) and "visual mental imagery" (e.g., having thoughts in the shape of images) have comprised a major focus of spontaneous cognition/mind wandering [3]. This current study focused on the domain of inner language and used the support vector machine (SVM) to investigate whether we could decode the whole-brain RSFC patterns and used the SVM structure to predict and classify individuals who reported inner language as the dominant mental activity during rs-fMRI scan from those who did not. This study can potentially lead to a better understanding of variations in rs-fMRI signals and their dependence on the spontaneous cognition/mind wandering.

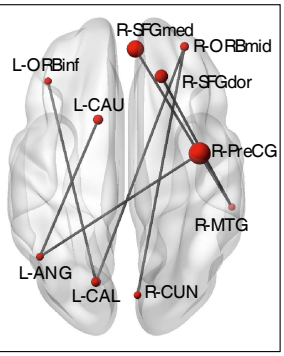
**Methods**
The study's participants included 18 healthy right-handed adults (mean age 29 $\pm$ 6 years, 9 males). All of the participants provided informed written consent, and the local ethical committee approved the study. Rs-FMRI was performed on a 3 Tesla GE scanner for 296s (T2*-EPI, sequence parameters: 74 volumes, TR=4s; TE=35ms; flip angle=90°; 56 axial slices; 1.5x1.5x3 $mm^3$ voxel size). Participants were instructed to lie still and fixate a centrally located crosshair. The functional acquisition was immediately followed by a debriefing interview using the ReSQ [3] to assess whether inner language was the dominant spontaneous thought content during the rs-fMRI scan. The rs-fMRI images were preprocessed (including slice time correction, motion correction, normalization to the Montreal Neurological Institute space, regression out the six motion parameters and white matter/cerebrospinal fluid signals, and low-pass filter) and parceled into 45 cerebral regions in each hemisphere [4]. Functional connectivity between each pair of regions was estimated using Pearson's correlation coefficient. Thus, for each participant, we obtained a 90 x 90 RSFC matrix with 4005 [i.e., (90x89)/2] unique elements. We then used the behavior-based connectivity analysis (BBCA)[5] to identify inter-regional links of which the connectivity strength was best correlated with the estimated time spent on inner language during the rs-fMRI scans. Once the links were identified, the SVMs were employed to construct the SVM structure. We then used a leave-one-out cross-validation strategy to estimate the generalization ability of our classifier, and the performance of a classifier was assessed in terms of both sensitivity and specificity. Finally, we employed the permutation tests 5000 times by randomly choosing subsets of links from the 4005 links (keeping the size of the network the same as the BBCA-identified network) to estimate the statistical significance of the observed classification accuracy.

**Results**
On average, the participants reported spending 33% of time on inner language (SD = 24.5%, [min, max]=[0, 85%]). The remaining time was filled with a mixture of thoughts related to visual mental imagery (21%), somatosensory awareness (22%), inner musical experience (15%), and mental manipulation of numbers (9%). Among the 18 participants, eight participants reported inner language as their dominant mental activity. Using BBCA, we identified a set of seven links with a significant, positive correlation to the time spent on inner language (adjusted $p < 4x10^{-5}$ with a minimum link clustering value of 2), representing longer time spent on inner language associated with stronger connectivity strength (Figure). Using the leave-one-out cross-validation and 5000 permutations, the SVM structure achieved a sensitivity of 0.88 ($p = 0.001$) and a specificity of 0.9 ($p = 0.004$) to classify individuals who reported inner language as the dominant mental activity during rs-fMRI scan from those who did not.

**Discussion**
The present results implicate a distributed cortical network in spontaneous cognition associated with inner language during rs-fMRI. One of the links was connected to left ORBinf, which is important in speech-language production. Additional connectivity was found in brain regions (including MTG, SFGmed, and ANG) that have previously been linked to spontaneous thoughts [6]. Interestingly, the connectivity strength between orbitofrontal and visual cortex was positively correlated with the time spent on inner language. Given that it has been suggested that orbitofrontal cortex is involved in suppressing presently irrelevant memories to monitor ongoing reality in thought [7], future research will be needed to investigate the role visual cortex plays in spontaneous cognition.

**Conclusion**
This study demonstrates that BBCA and SVM methods can be used to classify individuals who reported inner language as the dominant mental activity during rs-fMRI scan from those who did not with a sensitivity of 0.88 and a specificity of 0.9. The majority of the most discriminating functional links were connected to regions involved in spontaneous cognition and monitoring ongoing reality in thought. To assess whether the dominant mental states can indeed be reliably classified, investigations are underway in a second, independent cohort of participants using the same links and SVM structure. We are also investigating whether our findings can be extended to different domains of mental activities. It is anticipated that our approach can help discern the various components of resting brain signal, better characterize the resting state and increase the comparability among participants.

| Connected Regions | | *r* |
|---|---|---|
| R-MTG | R-SFGdor | 0.73 |
| R-MTG | R-SFGmed | 0.74 |
| R-ORBmid | R-CUN | 0.72 |
| R-ORBmid | L-CAL | 0.77 |
| L-ORBinf | L-CAL | 0.70 |
| L-ANG | R-PreCG | 0.71 |
| L-ANG | L-CAU | 0.73 |




Note. *r* = correlation between connectivity and the time spent on inner language; MTG = middle temporal gyrus; SFGdor = superior frontal gyrus, dorsolateral part; SFGmed = superior frontal gyrus, medial part; ORBmid = middle frontal gyrus, orbital part; ORBinf = inferior frontal gyrus, orbital part; CUN = cuneus; CAL = calcarine sulcus; ANG = angular gyrus; PreCG = precentral gyrus; CAU = caudate nucleus.

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