# Towards a taxonomy of attention shifting: Individual differences in fMRI during multiple shift types

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## Introduction

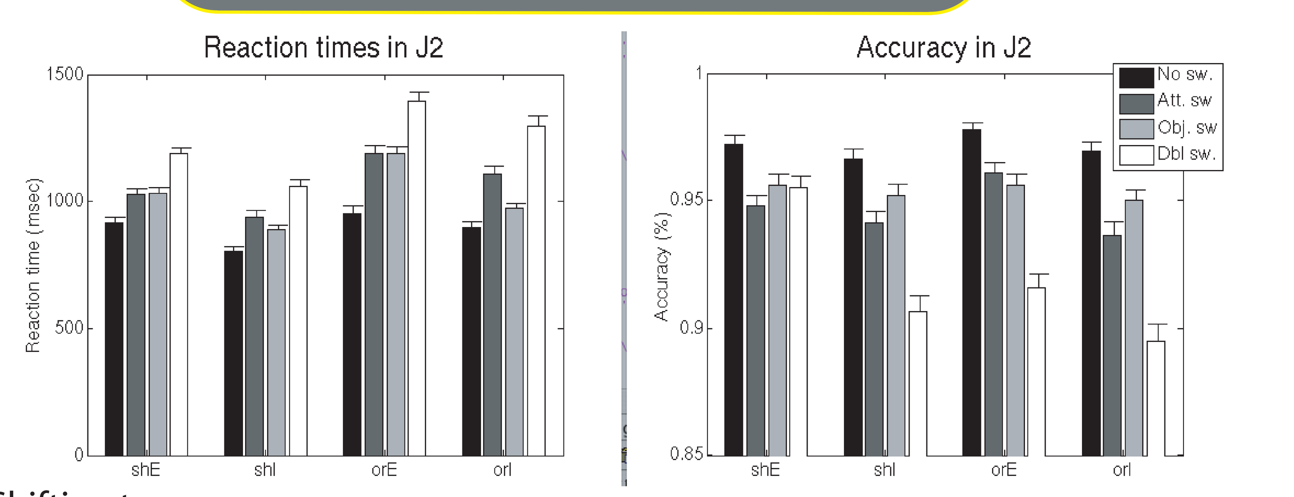
Task switching is often considered one of the fundamental abilities underlying executive functioning and general intelligence. But do different types of task and attention shifts use the same underlying mechanisms? Are performance measures correlated across shifting types? And what is the relationship between attention-shifting measures and other measures of "executive function?"

Our previous work, shown in the figure below, found a set of regions in the anterior insula/frontal operculum and frontal cortex that correlated with each other and with response-interference performance in three separate 'inhibitory' tasks: Go-No Go, a stimulus-response compatibility task (SRC), and a Flanker task. Poor performers showed more activity in these frontal regions in each task, but performance across tasks was relatively uncorrelated. Meta-analyses showed consistent activity across studies in all of these regions except insula for executive working memory, and for insula and anterior cingulate (but not anterior PFC) in task switching.

In this study, we examined individual differences in multiple types of attention-shifting to ask whether behavioral performance and fMRI activity are correlated across different types of shifting. Participants (n = 39) switched between objects and attributes both when stimuli were perceptually available (external) and when stimuli were stored in memory (internal). As in our previous work, we found that switch-related activations in many regions associated with executive control—including dorsolateral and medial prefrontal and parietal cortices—were more active when behavioral switch costs were higher (poor performers). Conversely, activation in ventromedial prefrontal cortex (VMPFC) and rostral anterior cingulate were consistently correlated with good performance, suggesting a general role for these areas in efficient attention shifting. Focusing on the VMPFC results, we suggest that reward-related signals in VMPFC may guide efficient selection of tasks in lateral prefrontal and parietal cortices.

This poster is available at http://www.columbia.edu/cu/psychology/tor/

## Performance Results




Shifting types:
shE: external shape, shI: internal shape, orE: external orientation, orI: internal orientation

## Correlations in performance (n = 249)

**Attribute switching in J2**

| | shE | shI | orE |
|---|---|---|---|
| shE | - | | |
| shI | 0.203* | - | |
| orE | 0.303* | 0.262* | - |
| orI | 0.173* | 0.362* | 0.371* |

**Object switching (residual)**

| | shE | shI | orE |
|---|---|---|---|
| shE | - | | |
| shI | 0.175* | - | |
| orE | 0.247* | 0.102 | - |
| orI | 0.07 | 0.303* | 0.207* |

o Significant object and attribute switching costs in second judgment (J2) for both internal and external tasks. True for both RT and accuracy.

Costs were 80 ms / 157 ms for external/internal object switching, and 81 ms / 109 ms for external/internal attribute switching ($F(1,41) = 88.5$, $p < .001$ for object, $F(1,41) = 25.2$, $p < .001$ for attribute). Object and attribute switching interacted, with dual-switch trials taking particularly long, in the internal task (58 ms interaction, $F(1,41) = 12.7$, $p = .001$) but not the external task (-13 ms, $F < 1$).

o An interpretation: Serial object and attribute selection processes in perception. But working memory involves refreshing objects and attributes, so serial selection is impossible.

o Significant object switch cost in the cue period.

o Overall J2 switch-costs showed a high odd-even split half reliability ($r = .99$) and a reasonable test-retest reliability across a period of weeks to several months ($r = .72$). We used actual switch costs in brain analyses.

o Correlations are higher within internal/external switching, implying that some unique processes are involved in switching perceptually vs. in working memory

red: vary internal/external and shape/orientation judgment
green: hold int/ext constant
blue: hold sh/or constant

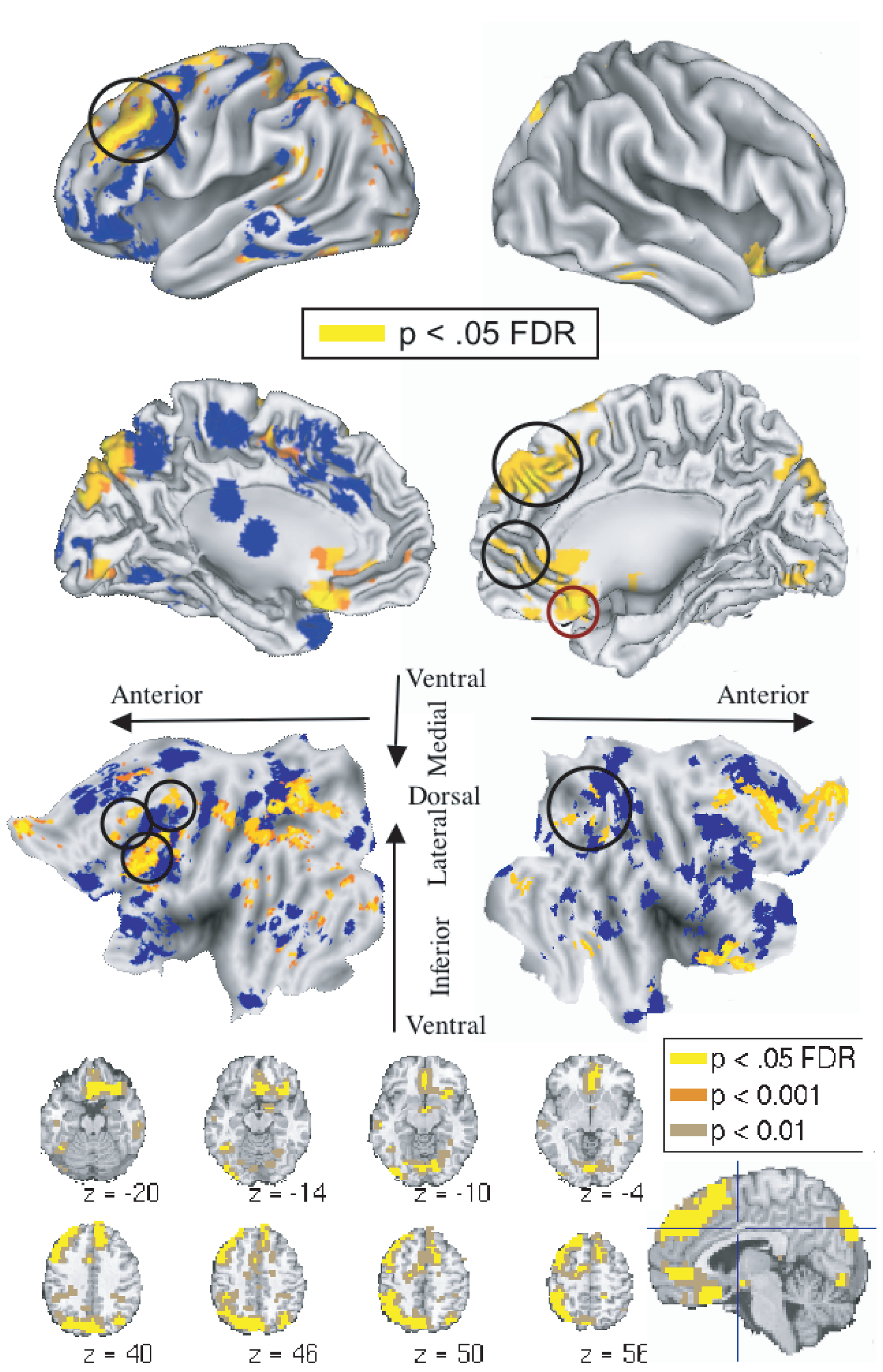
## Brain-performance correlations

**o Omnibus F-test for correlations between brain and behavioral switching costs, $p < .05$ FDR correction (yellow, $F > 3.52$, $p < .003$ uncorrected). $p < .01$ shown in tan.**

**o Positive fMRI-performance correlations in frontal, parietal (intraparietal sulcus and precuneus), and occipital regions. Strongest correlations with switches involving task-set**

**o Negative correlations in ventromedial PFC, pregenual anterior cingulate, and right inferior anterior insula (agranular insula near primary gustatory cortex; Mesulam & Mufson, 1982).**

**o Substantial overlap with working memory meta-analysis regions (shown in blue; Wager & Smith, 2003).**



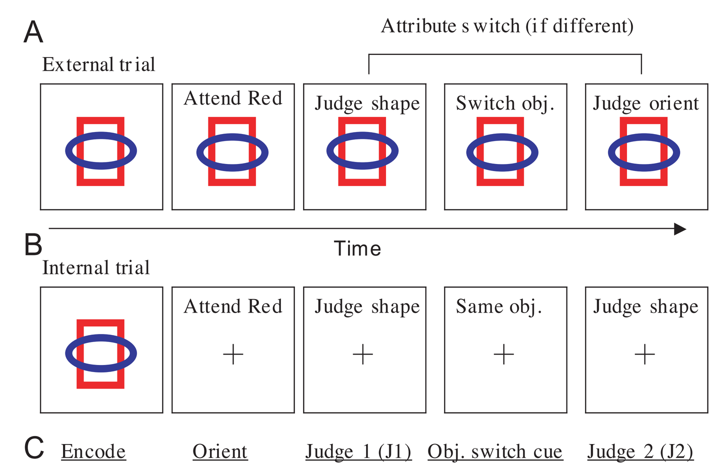

| | Task-set (goal) shift | | | | Rule (residual) shift | |
|---|---|---|---|---|---|---|
| | Object - Cue | | Attribute | | Object - residual | |
| | External | Internal | External | Internal | External | Internal |
| **Consistent negative correlations with rule shifting** | | | | | | |
| Ventromedial PFC | -0.45 | -0.46 | -0.55 | -0.38 | 0.53/-0.36 | -0.43 |
| Pregenual anterior cingulate | -0.56 | -0.39 | -0.53 | -0.44 | 0.33/-0.50 | -0.46 |
| **Consistent positive correlations with task-set shifting** | | | | | | |
| L anterior IPS | 0.44 | 0.47/-0.32 | 0.37 | 0.49 | -- | -0.45 |
| L DLPFC | 0.6 | 0.65 | 0.36/-0.36 | 0.58 | 0.39 | -0.41 |
| **Positive correlations with internal / task-set object shifting** | | | | | | |
| L fusiform | 0.48 | 0.49 | -- | 0.4 | -- | -0.43 |
| L visual cortex | 0.6 | 0.43 | -- | 0.33 | -- | -- |
| R visual cortex | 0.63 | 0.46 | -- | 0.38 | -- | -- |
| L intraparietal sulcus | 0.73 | 0.54 | -- | 0.53 | 0.32 | -0.41 |
| Precuneus | 0.43 | 0.54 | -0.33 | 0.41 | 0.32 | -0.49 |
| L precuneus / IPS | 0.55 | 0.45 | -0.34 | 0.51 | -- | -0.49 |
| L parietal cortex | 0.73 | 0.5 | -0.54 | 0.46 | -- | -0.61 |
| L posterior middle frontal gyrus | 0.59 | 0.71 | -- | 0.56 | 0.38 | -0.46 |
| L sup frontal gyrus | 0.51 | 0.48 | -- | 0.57 | -- | -0.62 |
| R medial frontal gyrus | 0.44/-0.34 | 0.61 | -0.58 | 0.39/-0.34 | -- | -0.45 |
| R IPS | 0.57 | 0.4 | -0.32 | 0.57 | -- | -0.51 |
| R sup cerebellar hemisphere | -- | 0.34 | -0.35 | 0.58 | -- | -- |
| L ant superior cerebellum | -- | 0.49 | -- | 0.49 | 0.36 | -0.4 |

## Methods

**Participants**
43 right-handed adults aged 18 – 40. The study was approved by the University of Michigan Institutional Review Board. Participants were selected from the **extreme ends (top and bottom 25%)** of a larger sample (n = 268) based on overall switch costs across conditions. After screening for head motion, quality of spatial normalization, and performance, analyses were conducted on a sample of n = 39 (n = 19 low switch cost and n = 20 high switch cost).

**Task design**
o Multi-part trials requiring two judgments about the same stimulus. Stimuli were images of two overlapping objects (ellipse and rectangle), one red and one blue. The color served as a cue for which object to attend. Judgments were made about whether the attended object was oriented vertically or horizontally, or whether the attended object was a rectangle or ellipse. The second judgment could involve a switch in attended object, judgment type, both, or neither (a 2 x 2 design).
o Blocks of 48 external (E) and internal (I) trials were alternately performed (E I E I E I), with two blocks of practice preceding test blocks.
o Trial ordering was optimized using a genetic algorithm (Wager & Nichols, 2003).

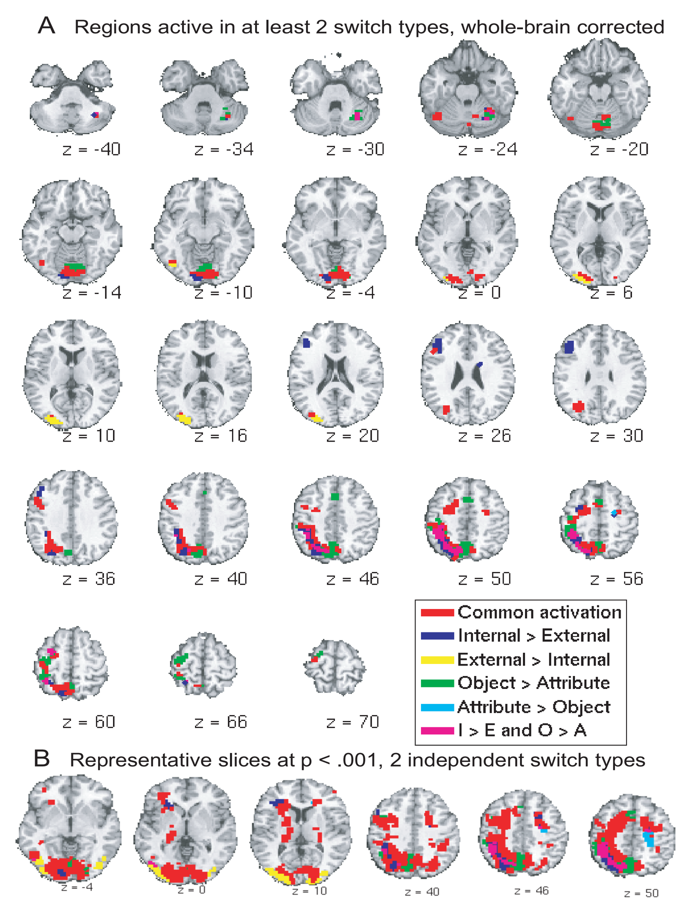
| Contrast | Process: When: Task-set shift | Process: When: Rule shift | Content: Type of representation: Object | Content: Type of representation: Attribute | Content: Locus of representation: Perception (external) | Content: Locus of representation: Working Memory (internal) |
|---|---|---|---|---|---|---|
| Object switch external in Cue period | ✓ | | ✓ | | ✓ | |
| Object switch internal in Cue period | ✓ | | ✓ | | | ✓ |
| Object switch external in J2 | | ✓ | ✓ | | ✓ | |
| Object switch internal in J2 | | ✓ | ✓ | | | ✓ |
| Attribute switch external in J2 | ✓ | ✓ | | ✓ | ✓ | |
| Attribute switch internal in J2 | ✓ | ✓ | | ✓ | | ✓ |




**fMRI acquisition and preprocessing**
o GE Signa 3T scanner at TR = 1.5, TE = 20, Flip = 90, 64 x 64 matrix, 3.75 x 3.75 x 5 mm voxels, skip 0. 26 slices provided whole-brain coverage.
o Slice acquisition timing correction, motion correction (Jenkinson, Bannister, Brady, & Smith, 2002), spatial normalization (to MNI; Ashburner & Friston, 1997), and 9 mm FWHM smoothing.

**Individual subject models**
o SPM2, with a canonical HRF used to model J2 events for each switch type (no switch, attribute switch only, object switch only, or double switch, crossed with internal and external conditions). Additional periods during the trial were also modeled, and these regressors were nearly orthogonal to the switch-related contrasts of interest. A high-pass filter cutoff of 1 / 180 Hz was used, with no global scaling.
o Contrasts were main effects of internal object switch (IO), internal attribute switch (IA), external object switch (EO), and external attribute switch (EA).

**Group analysis: Brain-behavior correlations**
o Second-level mixed GLM analysis in SPM2, 2-between, 4-within, to determine whether switch costs in each brain voxel were significantly predicted by behavioral performance measures.
o Six brain-behavior correlations interest: J2 cost with IO, IA, EO, and IA, and cue switch costs with IO and EO.
o Omnibus F-test to locate voxels with significant switch costs overall ($p < .05$ FDR-corrected; Genovese, Lazar, & Nichols, 2002). We examined the pattern of correlations across switch types for significant contiguous regions.




## Shifting activity

| Region | MNI Coordinates x | y | z | Voxels | Switch cost peak Z-scores OE | AE | OI | AI |
|---|---|---|---|---|---|---|---|---|
| Frontal cortex | | | | | | | | |
| L Premotor | -48 | 2 | 39 | 18 | 2.87* | 3.96* | 4.67* | 3.85* |
| L DLPFC | -45 | 28 | 27 | 38 | 2.18* | 3.83* | 5.29* | 3.79* |
| L Sup. Frontal Sulcus | -31 | -12 | 57 | 105 | 4.68* | 3.77* | 5.05* | 4.14* |
| R Sup. Frontal Sulcus | 25 | -10 | 52 | 9 | 2.78* | 4.46* | 4.45* | 4.09* |
| Anterior cingulate | -2 | 10 | 50 | 19 | 4.29* | 2.56* | 4.36* | 3.14* |
| Parietal cortex | | | | | | | | |
| L Precuneus | -11 | -71 | 50 | 198 | 5.16* | 2.99* | 4.66* | 4.41* |
| L Posterior IPS | -32 | -64 | 43 | 162 | 3.96* | 4.50* | 5.80* | 4.40* |
| L Anterior IPS | -41 | -41 | 51 | 121 | 4.09* | 4.24* | 5.57* | 4.08* |
| Basal ganglia | | | | | | | | |
| R Caudate | 19 | 0 | 25 | 1 | 1.94* | 2.78* | 4.26* | 3.50* |
| Occipital cortex | | | | | | | | |
| Occipital | -13 | -92 | -7 | 58 | 4.49* | 3.76* | 4.32* | 4.51* |
| Medial Occipital | 6 | -85 | -11 | 112 | 4.61* | 3.07* | 4.35* | 4.04* |
| L Extrastriate | -29 | -92 | 11 | 58 | 5.36* | 4.84* | 1.46 | 3.98* |
| L Inf. Occipital/Cerebellum | -45 | -67 | -19 | 17 | 3.54* | 4.53* | 2.71* | 3.88* |
| Cerebellum | | | | | | | | |
| Medial cerebellum | 8 | -65 | -21 | 8 | 2.92* | 1.46 | 4.60* | 3.71* |
| R Sup. Cerebellum | 30 | -62 | -29 | 30 | 3.98* | 2.10* | 4.95* | 3.79* |

**Identification of significant regions**
o Threshold Criteria: $p < .05$ corrected, SnPM with10 mm variance smoothing, in at least 2 of the 4 independent switch types (Panel A).

o Activation found in all task-switching regions associated from the meta-analysis, including bilateral IPS, premotor/SFS, anterior cingulate, precuneus, and left inferior temporal/occipital cortex. Also activations in left DLPFC and bilateral cerebellum, striate and extrastriate cortices.

o At lower thresholds, $p < .001$ in two or more switch types (Panel B), activity in bilateral parietal, left anterior insula and thalamus, bilateral putamen, hippocampus, and bilateral extrastriate cortex.

**Classification by switch-type preference**
o Within these regions, we classified voxels as common (showing no differences among switch types) or as preferentially responsive to some switch types with a mixed 2-between (behavioral switch costs), 2 x 2 within (object/attribute x internal/external) repeated measures ANOVA.

o Internal switch preference (blue): left DLPFC, IPS, and striate/medial extrastriate cortex
o External switch preference: bilateral lateral occipital cortex (yellow).
o Object preference: Medial structures, including anterior cingulate, precuneus, and cerebellar vermis, as well as left IPS and premotor cortex (green)
o Attribute preference: right sensorimotor cortex and SFS (cyan).

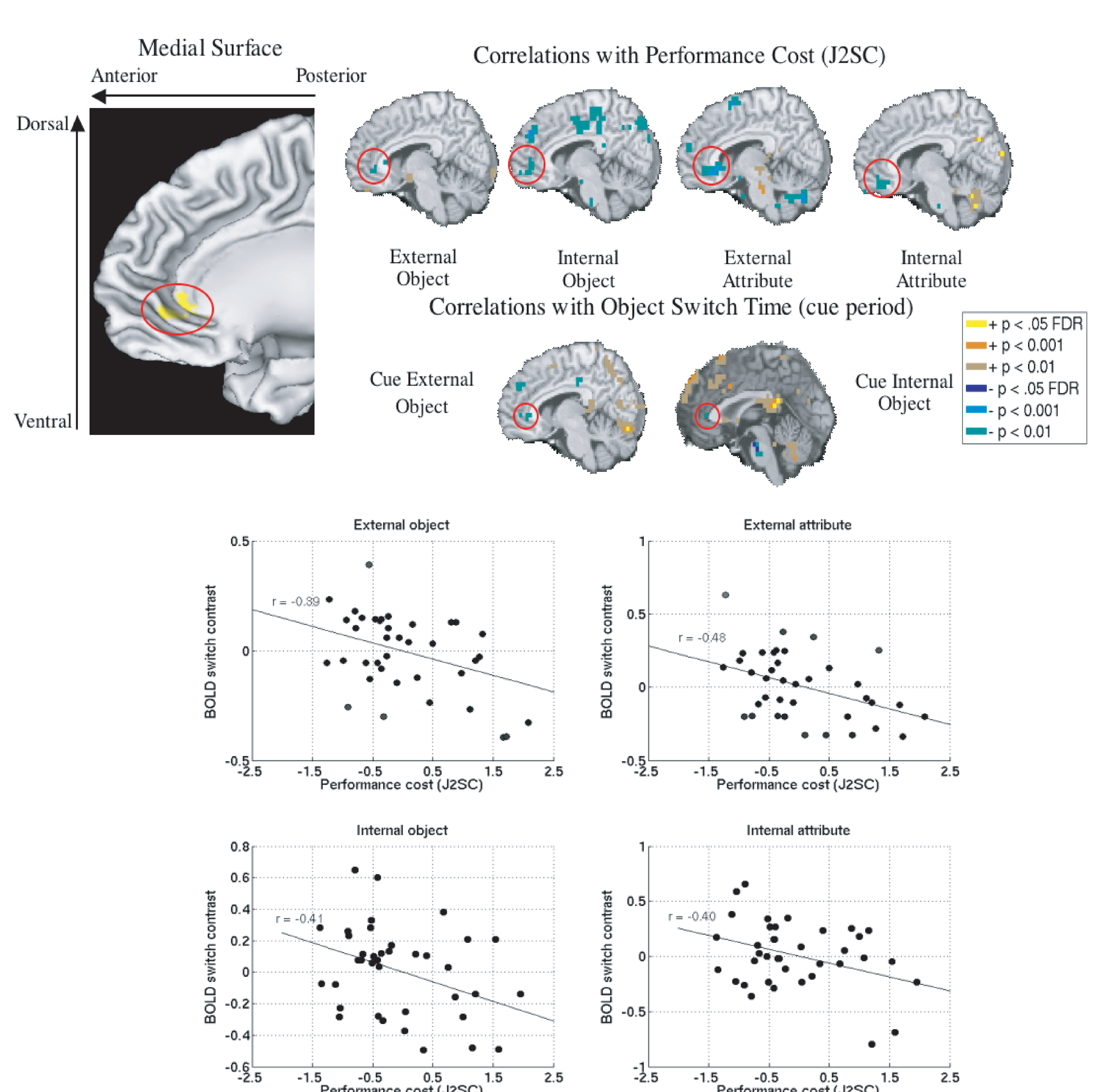
**Interpretation**
o There is both substantial commonality among different types of switch costs and evidence for switching type-specific effects.

o Greater frontal and parietal involvement in switching among WM representations may relate to scheduling demands on refreshing items in WM and selecting items for further processing.

o Perceptual switching activations in extrastriate cortex implicate posterior cortex in executive function, above and beyond simple perception or memory.

o Even 'simple' shifts of attention reflect a complex coordination of memory retrieval and scheduled mental

## Correlations in ventromedial PFC




**The ventromedial PFC has been associated in the animal literature with updating representations of value and reward that are used to guide decisions and/or inhibiting irrelevant responses after reward contingencies change (Wallis et al., 2001; Dias, Robbins, & Roberts, 1997; Everitt et al., 1999; Baxter, Parker, Lindner, Izquierdo, & Murray, 2000). This part of cortex appears to be necessary when changing reward contingencies signal shifts in attention (Fellows & Farah, 2003). .**

**The idea that changing valuations of stimuli drive shifts in attention provides a natural mechanism for "control input" in computational models, and our findings are consistent with this view.**

**An alternative is that ventromedial PFC may be part of a 'default' brain network that is active at rest and decreases with cognitive load (e.g., Gusnard & Raichle, 2001). However, a) ventromedial PFC was not consistently deactivated in task-switching overall; and b) the brain-behavior correlations are more consistent across switch types in this region that in dorsolateral cortex. It seems unlikely that decreases in VMPFC are a more reliable marker of load than increases in DLPFC.**

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