Neural Correlates of Conscious Flow during Medication

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Abstract

Human conscious flows can alter brain states. Such brain activities modulate energy consumptions, which can be manifest in the BOLD effect in fMRI experiment. The goal of this study is to identify whether there is difference in such BOLD effects between experienced Tai Chi master in meditation state and normal control subjects. In this experiment, both the meditator and the controls using their conscious to lead a flow periodically circling in their brain in axial, sagittal, and coronal orientations inside a MRI scanner. The experimental results showed significant differences between the meditator and the controls. The most important one is that the meditator activates frontal medial cortex and precuneous regions without any visual excitation, while the controls only utilize visual cortex and precuneous regions without any frontal medial excitation. These seems suggest that for performing the same tasks, the meditator is in cognitive control state, while the controls are in spatial imagination state.

Introduction

By withdrawing from external world, meditation could re-channel human internal energy to improve mental and physical wellbeing. Although it has been practiced for centuries, a scientific description of meditation is still elusive due to lack of objective methods to either characterize mental states or gauge meditation contexts. The fMRI offers a non-invasive way to observe brain activities, it can be used to study how meditation altering brain states (Tang et al., 2015; Wang et al., 2011).

Brain state changes will demand energy consumption, which will trigger cerebral blood flow elevation. The variations of the oxyhemoglobin versus deoxyhemoglobin ratio in capillaries due to such blood flow increase can be measured by fMRI BOLD effect (Ogawa et al., 1990). It has been shown that meditation can result in cerebral blood flow increase or re-distribution (Jevning et al., 1996; Khalsa et al., 2009). Thus the brain state changes during meditation should be able to be characterized by fMRI. Comparing to other methods, such as EEG (Cahn and Polich, 2006), fMRI offers substantial spatial resolution.

Throughout history and across the whole world, there have been many schools of teaching and thoughts on practicing meditation. In this study, the subject-under-test follows Daoism, whose focus in meditation is to control "Qi" – a form of invisible energy emitted from nature. The Qi meditation circulates Qi inside human body, unifies mind and body, and contemplates wellbeing. In this experiment, the cerebral blood flow increases induced by conscious-guided Qi movements were measured by fMRI. It offers an energy consumption map in cerebrum during meditation. Comparing the results from both meditator and controls that performed the same tasks, some dramatic differences were identified.

Methods

Experimental Design

The experimental design is to have participants periodically circulating their conscious flows inside their brains in axial, sagittal, and coronal orientations with their eyes closed, in which human conscious, spatial imaginations, and mental movements are intrinsically integrated together. The participants are divided in two groups: the experienced meditator (Tai Chi master) and the controls (people do not practice meditation). Although both groups perform the same task, the distinction between the two groups is that the meditator's conscious flow was able to guide the "Qi" while the controls were not able to.

In this case study, fMRI is used to observe the BOLD effects of such flows of "Qi" and "non Qi" in three different trajectories: circling in axial, sagittal, and coronal planes. The Tai Chi master with more than 30 years practice participated this study in eight study sessions, each session consists of two trials. Total 15 trials data were collected in a period of two months. Meanwhile, total 11 trials of the controls were also collected. All participants gave informed and written consent based on the approval of the institutional review board in the Princeton University.

Data acquisitions

The fMRI experiment is conducted with a block design. There are five blocks in one period: relaxing, fixating on most frontal end of brain, circling the conscious flows in axial, sagittal, and coronal orientations. There are total five periods in each trial. Given that one whole brain volume sampling time is 2s, each block has 10 sampling volumes (20s), each period has 50 volumes (100s), and each trial has 250 volumes (8min 33second). All participants had their eyes closed during all scan sessions.

The experiment was conducted on a Siemens 3T MRI scanner, MAGNETON Prisma (Erlangen, Germany), with 64-ch head/neck coil. The fMRI data acquisition sequence is EPI, TR 2s, TE 30s, voxel size 2x2x3mm^3, field-of-view 192x192mm^2, frequency and phase read-out resolutions 96x96, slice thickness 3mm, slice number 32, slice distance factor 20%, iPAT factor 3, and read-out bandwidth 1064Hz/pixel. Besides functional data, an anatomical data was acquired with MPRAGE sequence for brain registration. A field map was also acquired with gradient echo sequence for static magnetic field inhomogeneity correction.

Data post-processing

The BOLD responses for the four tasks (1. focusing, 2. axial, 3. sagittal, and 4. coronal circling) were calculated by group analysis of general-linear-model (GLM) regression. The comparisons between the meditator and the control groups were estimated by paired t-test comparison. Both were implemented by the software package FSL (Oxford University, UK) (Jezzard et al., 2001).

In the preprocessing, all functional data sets from both meditator and controls were put through motion correction, slice time correction, and brain extraction, as well as spatial smoothing with HMFW 5mm and temporal high pass filtering with a cut-off period of 100s. All anatomical and field mapping data sets were also put through bias field correction and brain extraction. All the functional data sets were first registered to their corresponding anatomical data sets, and then registered to the standard MNI152 template (Mazziotta et al., 1995) for both group analysis and atlas labeling. The cerebral parcellation and labeling were based on the built-in Harvard-Oxford Cortical and Subcortical Structural Atlas (Desikan et al., 2006).

To get the baseline, the GLM's regressor is set to ON during the focusing block, and set to OFF during the relaxing and the three circling blocks. For both meditator and controls, their brain's spatial imagination was a singular point, and no mental movement was involved in this situation. The group average of the 15 trials of meditator's data and the group average of the 11 trials of the controls' data were calculated separately, and yielded the baseline BOLD responses for both meditator and controls respectively.

To extract the common responses to the mental circling tasks from both meditator and the controls, three regressors were applied in the GLM. They are set to ON during axial, sagittal, and coronal circling period respectively, and set to OFF during the rest of the period respectively as well. The averaging process took two steps: first, for each trial's data, all three regressions were averaged to form a "3-dimension (3D)" response; second, the "3D" responses of all 26 trials (including meditator's and controls' data) were averaged. The result was an estimation of how general people (meditator and non-meditator alike) responded to the mental circling tasks without consideration of the "Qi" element.

Finally, to identify the different BOLD responses between meditation and no meditation, the GLM applied the three regressors for the three orientations, as well as the 3D average, to the meditation and control groups separately. The group average of the meditator's 15 trials of data yielded average BOLD responses to axial, sagittal, coronal, and 3D mental circling respectively during meditation. Whereas the group average of the controls' 11 trials of data yield average BOLD responses to axial, sagittal, coronal, and 3D mental circling respectively without meditation. Most importantly, the mixed effects of the unpaired t-test comparison between meditator's 15 trials and controls' 11 trials demonstrated the significant differences between having "Qi" and having "no-Qi" in the conscious-guided mental circling.

Results

Baseline

Before investigating BOLD effects of conscious-guided mental circling, some baseline data were acquired for each trial, in which participants set their brain to focus on a point at the front end of their brain. In this case, both spatial and mobile imaginations were reduced into a singular point. Even for such degenerated case, the brain states in meditation and non-meditation are quite different, as shown in Figure 1. Figure 1A suggests that meditator was able to channel the energy directly to the focal point without recruiting any other brain system. Whereas Figure 1B suggests that imaginations of focusing on a frontal point by the controls do not directly channel the energy to that physical point, in stead they mostly recruit visual and sensorimotor cortices to construct such imagination. Note that a slight activation on left lateral frontal cortex in both A and B are the response of verbal commands during the test.

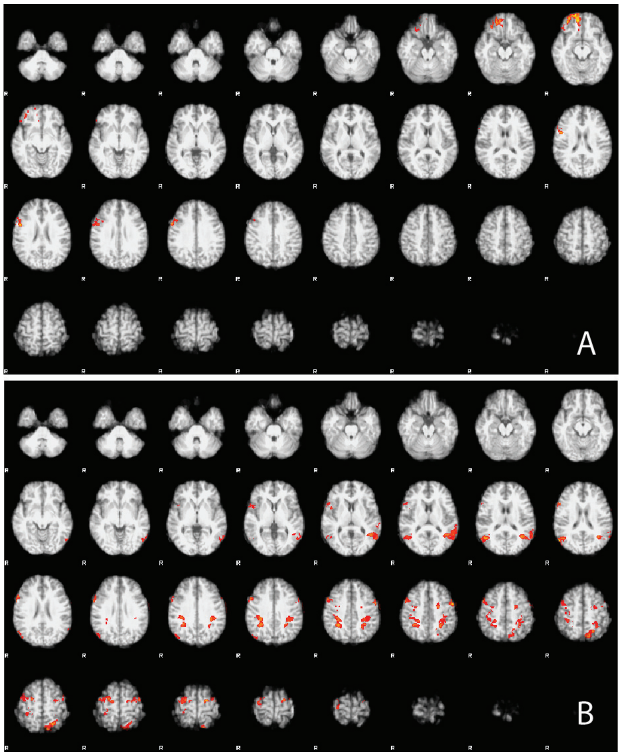

Figure 1. The group average BOLD responses when the conscious focus on a singular point in front end of brains by meditator in meditation state (A), and by controls in non-meditation state (B). (Z-score>2.3, p-value<0.05)

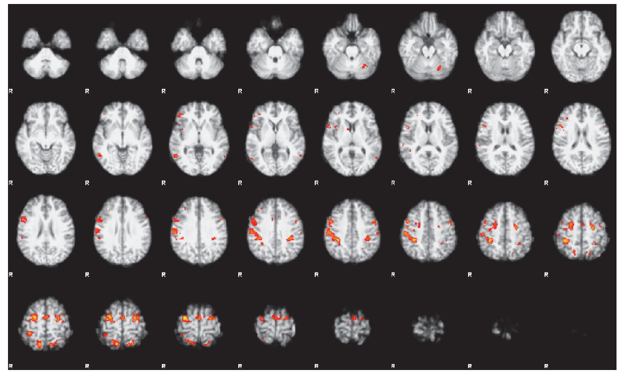

Figure 2. The group average BOLD effect for all three orientations mental circling tasks from both meditation and non-meditation groups. (Z-score>4.9, p-value<0.01)

Tab .1

	Voxels	max X	max Y	max Z	cog X	cog Y	cog Z
Frontal lobe:							
F1	218	33	64	60	31.9	61.5	64.6
	207	56	60	60	57.1	60.5	66.7
F2	225	29	63	60	29.3	62.8	65.2
	197	58	61	59	60.8	61.9	65.3
	109	21	67	53	20.3	66.8	57.3
F3o	221	17	72	35	18.4	69.8	44.6
Sensorimotor & visual cortex:							
PRG	460	27	55	57	28.9	58.5	65.1
	460	15	68	43	18.5	65.6	53.6
	326	58	58	59	59.8	59	65.7
SMC	344	46	63	61	45.1	60.8	67.5
POG	622	13	55	49	19.8	51.2	56.2
	59	61	44	55	63.6	45.9	56.1
LOs	336	36	26	62	35.6	30.3	65.6
	218	54	29	60	53.9	29.4	65
Parietal lobe:							
SPL	392	28	39	55	26.3	42.3	61.7
SGa	444	13	55	49	18.8	50.4	55.9
SGp	216	18	45	49	24.1	43.7	58.2

Common responses to the tasks

Given that both the meditator and the controls responded the same mental circling requests, they shared some common brain states, which indicated that they were dealing with the same task at certain level. Such common responses for all three orientations mental circling tasks from both meditation and non-meditation groups are shown in Figure 2, and labeled in Table 1. Notice that a symmetric and stable pattern is statistically highly significant ($Z>4.9$, $p<0.01$)) in Figure 2 and is highlighted in Table 1, which consists of bilateral precentral gyrus (PRG, primary motor cortex), postcentral gyrus (POG, primary somatosensory cortex), superior lateral occipital gyrus (LOs, extrastriate visual cortex), as well as medial juxtapositional lobule (SMC, supplementary motor cortex). This clearly indicates that the mental circling tasks recruit sensory, motor, and extrastrate visual cortices in both meditation and non-meditation cases. Note that the midline brain, such as frontal medial cortex (FMC) and precuneous (PCN) and cingulate (CG), are largely missing in the common responses.

Difference in meditation and non-meditation state

For each of the three mental circling tasks (axial, sagittal, coronal circling), its group averages and group t-test comparison between meditation and control group are shown in Figure 3, 4, and 5 respectively.

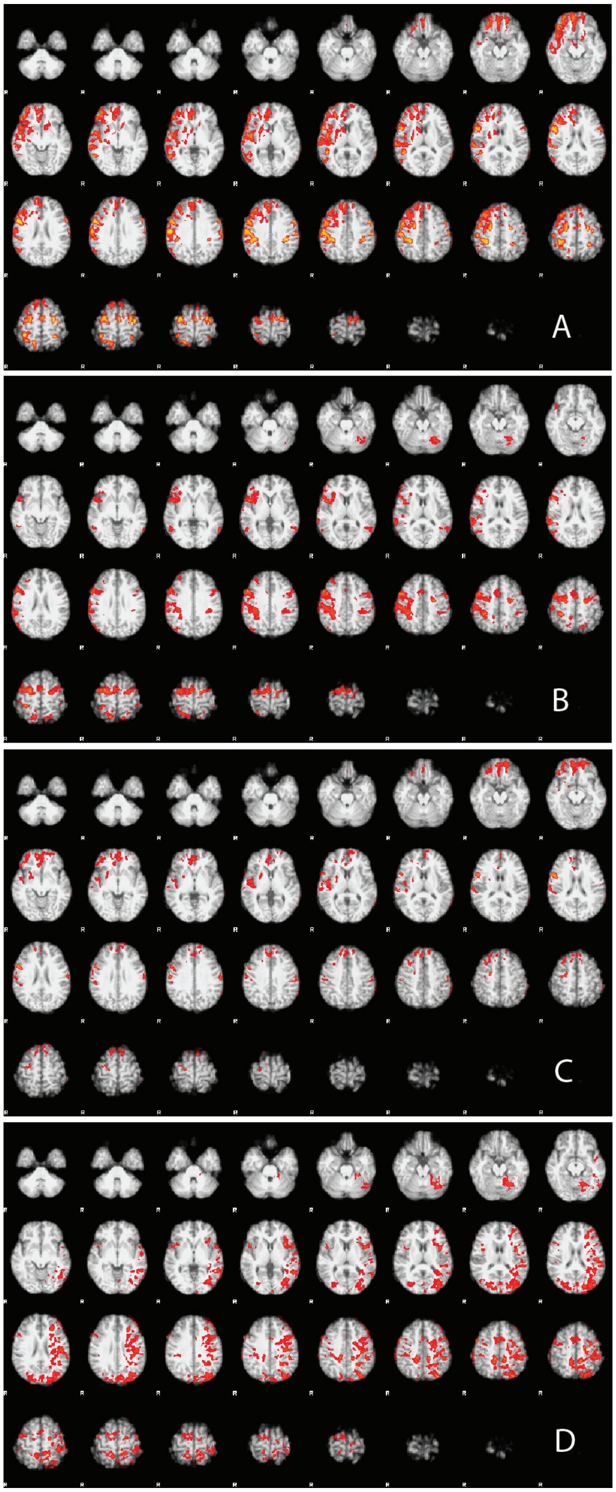

Figure 3 The BOLD response to axial circling for meditation (A), control (B), A-B (C), and B-A (D). (Z>2.3, p<0.05)

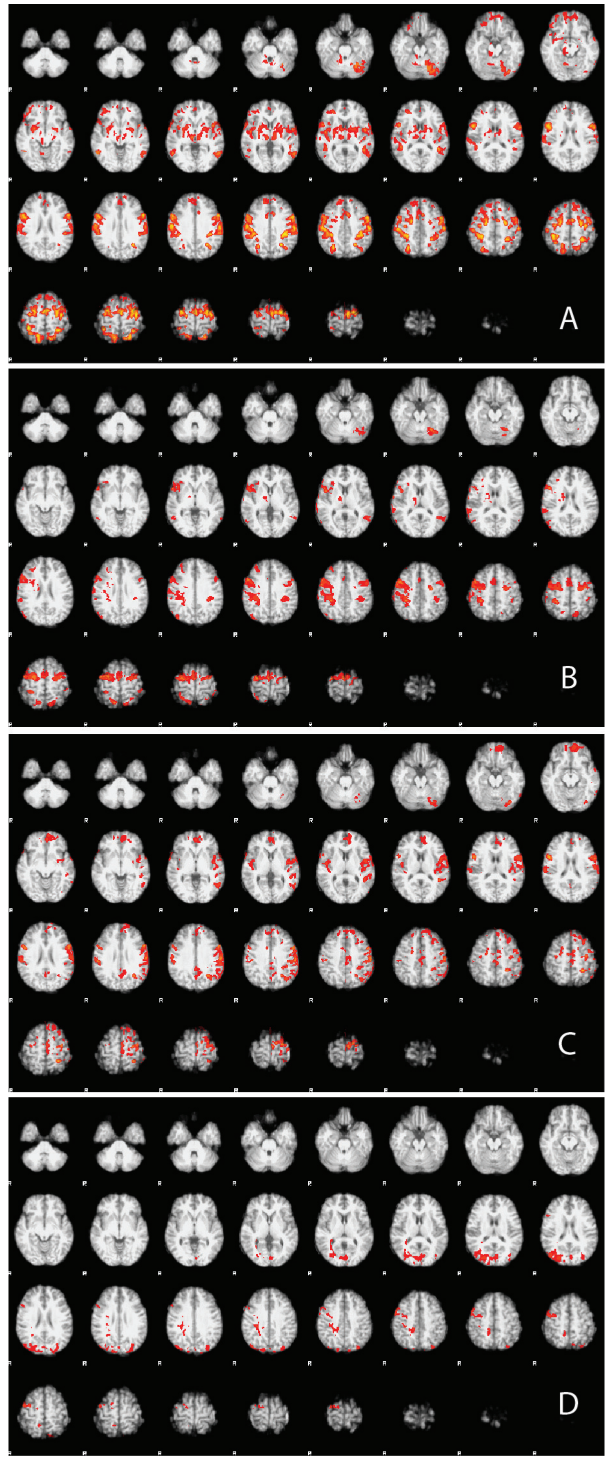

Figure 4 The BOLD response to sagittal circling for meditation (A), control (B), A-B (C), B-A (D). (Z>2.3, p<0.05)

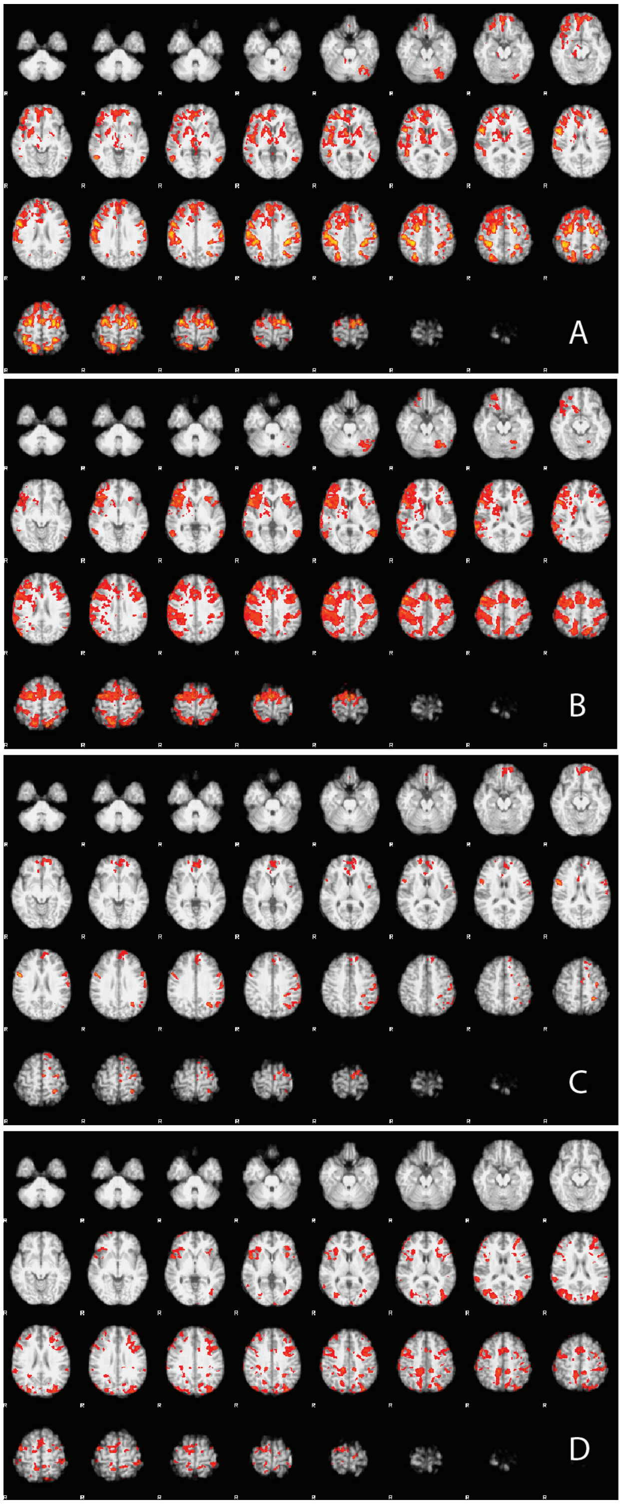

Figure 5 The BOLD response to coronal circling for meditation (A), control (B), A-B (C), B-A (D). (Z>2.3, p<0.05)

The detailed discussion on the differences between the three orientations may be beyond the scope of this paper, since the focus here is to compare brain states in meditation and control. Thus, the comparison between meditation and control group for all three orientations together (3D) are given in Figure 6. The detailed comparisons for "mediation > control" and "control > meditation" are labeled in Table 2 and Table 3 respectively.

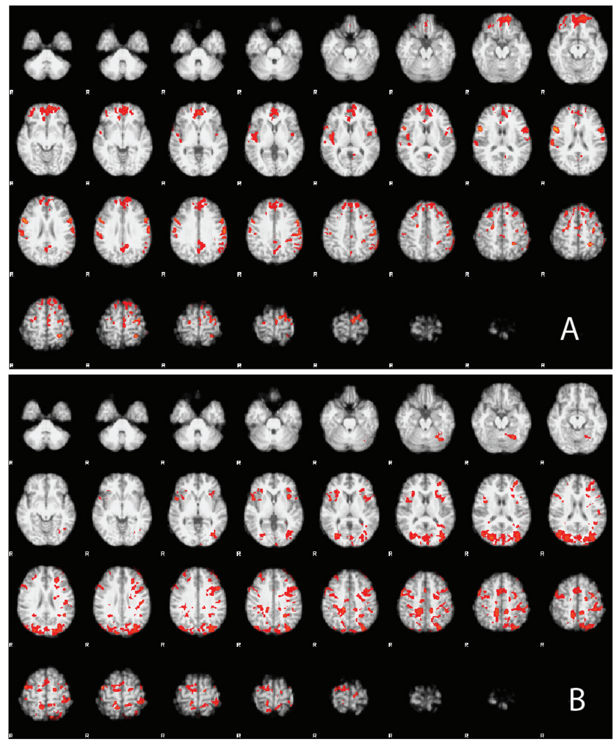

Figure 6 The t-test comparison for all three-orientation circling: (A) meditation–control, (B) control-meditation. (Z>2.3, p<0.05)

Apparently the meditator and the controls adapted different approaches to handle the mental circling tasks. As shown in Figure 6A and Table 2, the brain states in meditation showed dominant activations on frontal medial cortex, precuneous, anterior and posterior cingulate, which is a typical pattern for cognitive control. Whereas in Figure 6B and Table 3, the brain state of the controls showed most activations on almost entire visual cortex and precuneous, which seems to be the pattern of visual imagination, given that participants were closing their eyes during scans. Such mutual exclusive results on frontal medial cortex and occipital lobe seem to experimentally confirm a hypothesis that that the meditator was using his conscious to guide the flows of "Qi", whereas the controls were imagining the visual trajectories.

Tab. 2

	Voxel	max X	max Y	max Z	cog X	cog Y	cog Z
Medial anterior:							
FMC	574	44	82	24	44.7	87.6	30.5
FP	995	46	89	26	46.6	92	34
	480	51	97	47	51.3	87.9	55.1
	261	38	90	46	37.4	87	53.5
Cga	405	42	80	31	44.7	83.5	39.1
PAC	1160	42	81	29	45.2	86.5	41
Medial posterior:							
PCN	422	47	32	40	46.7	33.4	49.7
CGp	260	48	36	40	47.4	38	50.2
Lateral posterior:							
AG	210	71	35	49	71.7	34.9	53.9
Sga	267	12	52	45	15.8	51.4	50.9
	243	78	48	47	73.8	49.9	53.3
SGp	157	73	35	49	73.6	38.2	53.4
(SPL	277	59	41	56	59.9	39.1	63.3

T. 3

	Voxel	max X	max Y	max Z	cog X	cog Y	cog Z
Medial posterior:							
PCN	454	38	43	55	39.4	39.1	61.4
	256	51	43	56	49.7	40.8	62.3
CGp	138	38	44	54	39	44.6	57.4
	91	51	45	54	50.6	44.5	57.1
Occipital lobe:							
Los	1974	60	19	39	59.2	23.4	52.5
	1258	29	20	39	28.9	23.2	48.9
Loi	368	66	32	32	64.4	25	39.7
	183	29	20	38	25.5	24.9	42.2
Cli	264	46	22	38	44.7	23.2	42.1
CLs	262	46	20	39	45.1	22.2	43.2
CNL	531	44	19	41	46.8	22	48.5
	115	36	26	45	37.8	23.8	52.1
OP	1112	47	14	36	45.9	17.6	48.1

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