

# Understanding Consciousness from Information and Integration within the Thalamocortical System

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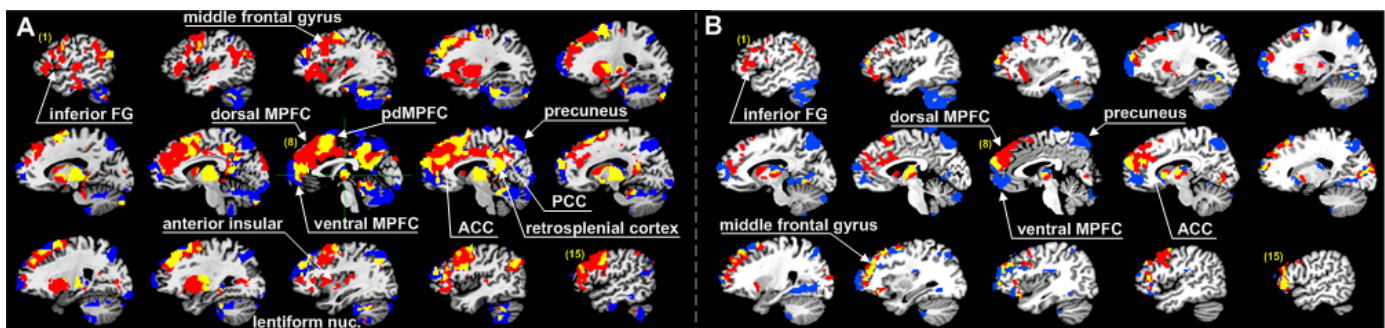
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**Introduction:** Understanding the neural mechanisms of consciousness requires identification of the nature of contributions from each of the potential neural correlates, which together generate a complete cognitive experience. Although in several pathological conditions marked by conscious incapacity (e.g., vegetative state, coma, anesthesia, etc), the disruption of consciousness can be linked to altered thalamocortical and corticocortical connections involving widely distributed brain regions in the frontoparietal network<sup>1,2</sup>, it is unclear what the impaired network connectivity exactly means to consciousness, and how the identified cortical regions contribute to the various symptoms of consciousness degradation. Here, we examined the specific and nonspecific thalamic connections in the brain based on the neuroanatomical findings implicating their respective functional roles in sustaining information and integration, which are essential to consciousness as suggested by a recent theory<sup>3</sup>. The hypothesis we sought to substantiate is that the specific thalamocortical connections are responsible for functional specialization (information), forming sensory representations from the content about the external world; in contrast, the nonspecific thalamocortical connections are responsible for information integration (likely together with memory retrieval) that eventually generate high-order cognitive perceptions.

**Methods:** Seven healthy volunteers and seven age-matched patients diagnosed with vegetative state participated in the study. Imaging acquisition was performed using a Siemens Trio 3T scanner in resting state. Functional axial images were obtained in a duration of 6 minutes using a single-shot gradient EPI pulse sequence (TE, 25 ms; TR, 2s; flip angle, 90°; number of slice, 25; slice thickness, 5 mm; slice spacing, 1 mm; matrix size, 64×64), followed by a scan of the high-resolution SPGR images. The nonspecific thalamic nuclei (i.e., the intralaminar nuclei including the CM and pF nuclei) and the rest of specific thalamic nuclei were manually drawn for functional connectivity analysis. Data preprocessing included slice-time correction, despiking, detrending, motion correction, and general linear model fitting that removes signals induced by motion parameters, white matter, and CSF. The residual signals were filtered to only preserve the low-frequency fluctuations within 0.015 to 0.1 Hz. Voxelwise Pearson cross-correlation analyses were performed across the whole brain. The results were registered and transformed into the Talairach space in 2-mm cubic voxels. Group contrasts were constructed by applying multiple 1/2-sample *t*-tests that were then converted to *z* values. All voxels survived at a *P*-threshold of 0.025 after the correction for multiple comparisons (*AlphaSim* in AFNI; cluster thresholding, 105 voxels).

**Results:** With healthy subjects, both the specific and nonspecific thalamocortical connections are widely distributed, but exhibit different patterns in the brain. VS patients demonstrated a significantly size-reduced connectivity with the specific and the nonspecific thalamic nuclei. The nonspecific thalamic connectivity suffered from a more severe reduction such that the ratio of survived voxels of specific connections in VS is 8.93 times larger than that of the nonspecific. A certain percentage of brain areas showed overlapping connections with both types of the thalamic nuclei (23.7% of one-sample *t*-tests of healthy subjects, and 8.61% of two-sample *t*-tests comparing subject groups). These results are illustrated in Figure 1.

**Discussion:** Our results demonstrated a consistent division of brain regions such that all the neural correlates that have been identified in association with high-order cognitive functions, are either predominantly (e.g., dorsal MPFC, AIC, IFG, ACC), or at least partially (e.g., PCC, retrosplenial cortex), connected with the nonspecific thalamic nuclei. Likewise, the specific thalamic connections were consistently revealed by brain regions presumably responsible for representing information about the external world. The findings suggest that the nonspecific thalamic connections with the dorsal prefrontal cortex (PFC) and anterior cingulate cortex for information integration, and the specific connections with the ventral PFC and precuneus for gathering information together contribute mostly to the loss of consciousness in VS. Overall, our results not only endorse the view that the thalamocortical system is essential to consciousness, but also support the hypothesis that the nonspecific thalamic connections largely reflect brain regions that are responsible for information integration, potentially sustaining various awareness functions.



**Figure 1.** Color map of brain regions showing the contrast between the specific (blue) and nonspecific (red) thalamic connections in subject groups. Overlapping areas were marked in yellow. (A) one-sample *t*-tests with healthy subjects. (B) two-sample *t*-tests between healthy and VS subjects.

## References:

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