Figures and figure supplements

The modulation of neural gain facilitates a transition between functional segregation and integration in the brain

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Figure 1. Manipulating neural gain. (a) the Yerkes-Dodson relationship linking activity in the locus coeruleus nucleus to cognitive performance; (b) neural gain is modeled by a parameter (σ) that increases the maximum slope of the transfer function between incoming and outgoing activity within a brain region; (c) excitability is modeled by a parameter (γ) that amplifies the level of output; (d) the approach presently used to estimate network topology from the biophysical model.

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Figure 2. Network Integration and Phase Synchrony. (a) mean participation as a function of $\sigma$ and $\gamma$; (b) phase synchrony ($\rho$) as a function of $\sigma$ and $\gamma$; (c) mean participation ($B_A$) aligned to the critical point (represented here as a dotted line) as a function of increasing $\gamma$; (d) $B_A$ aligned to the critical point as a function of increasing $\gamma$ – the left and right dotted lines depicts the synchrony change at low and high $\gamma$, respectively. The $y$-axis in (c) and (d) represents the distance in parameter space aligned to the critical point/bifurcation for either $\sigma$ ($\Delta\sigma_{CB}$; mean across $0.2 \leq \gamma \leq 0.6$) or $\gamma$ ($\Delta\gamma_{CB}$; mean across $0.3 \leq \sigma \leq 1.0$). Lines are colored according to the state of phase synchrony on either side of the bifurcation (blue: low synchrony; yellow: high synchrony). 
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Figure 2—figure supplement 1. Relationship between phase regimen boundary and alternative measures of network integration. (a-c) the inverse modularity ($Q^{-1}$) was maximal following the $\sigma$ boundary ($\Delta\sigma_{CB}$, mean across 0.2 $\leq \gamma \leq$ 0.6) and the immediately prior to the abrupt phase transition at high $\gamma$ ($\Delta\gamma_{CB}$, mean across 0.3 $\leq \sigma \leq$ 1.0); (d-f) global efficiency (G.E.) was maximally variable with increasing $\sigma$ and across the critical boundary at high $\gamma$.

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Figure 2—figure supplement 2. Standard deviation of the order parameter across the parameter space. (a) standard deviation of order parameter across the parameter space; (b) fluctuation scaling pre-boundary ($\sigma = 0.375$ and $\gamma = 0.50$); and (c) post-boundary ($\sigma = 0.50$ and $\gamma = 0.575$) – the thin blue line denotes a Pareto (i.e., power law) scaling effect.

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Figure 2—figure supplement 3. Transition to self-sustained oscillations in a single brain region. For the generic 2D oscillator model this shows the real parts of eigenvalues at equilibrium as the level of input (I_{app}) to a region is increased. A transition to self-sustained oscillations in a local region occurs where this curve crosses zero. That regime is bounded by supercritical Hopf bifurcations at I_{app} = 2.0 and I_{app} = 14.

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Figure 2—figure supplement 4. Average time-averaged connectivity matrix in regions of the parameter space associated with high (yellow) or low (blue) ordered phase synchrony.

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Figure 3. Topological and temporal relationships with phase regimen boundary. (a-c) network communicability was maximal following the σ boundary ($\Delta \sigma_{CB}$; mean across $0.2 \leq \gamma \leq 0.6$) and the immediately prior to the abrupt phase transition at high $\gamma$ ($\Delta \gamma_{CB}$; mean across $0.3 \leq \sigma \leq 1.0$); (d-f) time-resolved between-module participation ($B_T$) was maximally variable with increasing $\sigma$ and across the critical boundary at high $\gamma$.

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Figure 4. Regional clustering results. (a) regions from the CoCoMac data organized according to rich club (red), feeder (blue) or local (green) status, along with a force-directed plot of the top 10% of connections (aligned by hemisphere), colored according to structural hub connectivity status; (b) the rich club cluster demonstrated an increase in realized mean gain (the relative output as a function of its’ unique topology) at the bifurcation boundary, compared to feeder and local nodes, which showed higher realized gain at high levels of $s$ and $g$; (c) the three clusters of regions also demonstrated differential responses to neural gain; and (d) excitability. The black lines in (c) and (d) denote significant differences in $B_A$ between the two groups.

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Figure 4—figure supplement 1. Diverse Club. (a) regional differences in integration (BA) as a function of changes in neural gain; and (b) excitability, separated into regions within or outside the diverse club.
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Figure 4—figure supplement 2. Clustering coefficient. (a) clustering coefficient across the parameter space; (b) as a function of changes in neural gain; and (c) excitability.

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