Basal Forebrain Activation Enhances Cortical Coding of Natural Scenes

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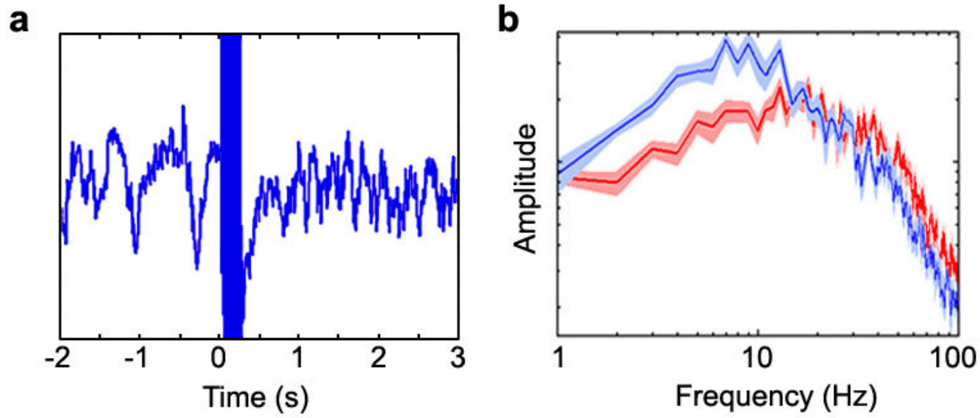
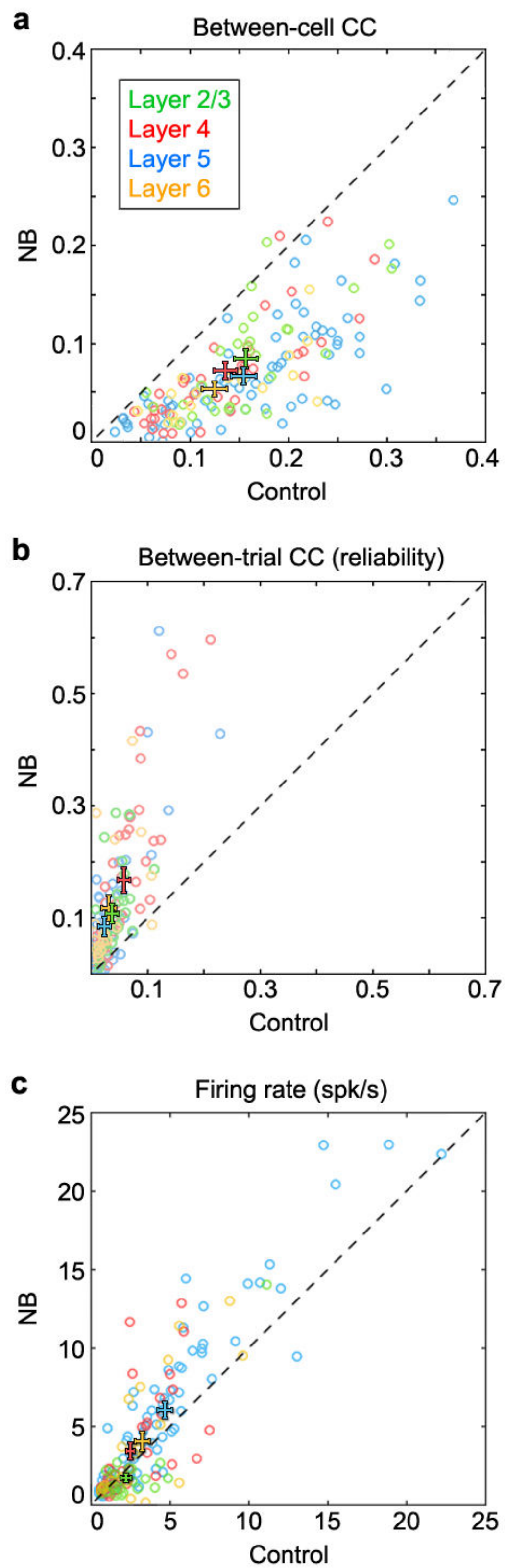
Supplemental Information

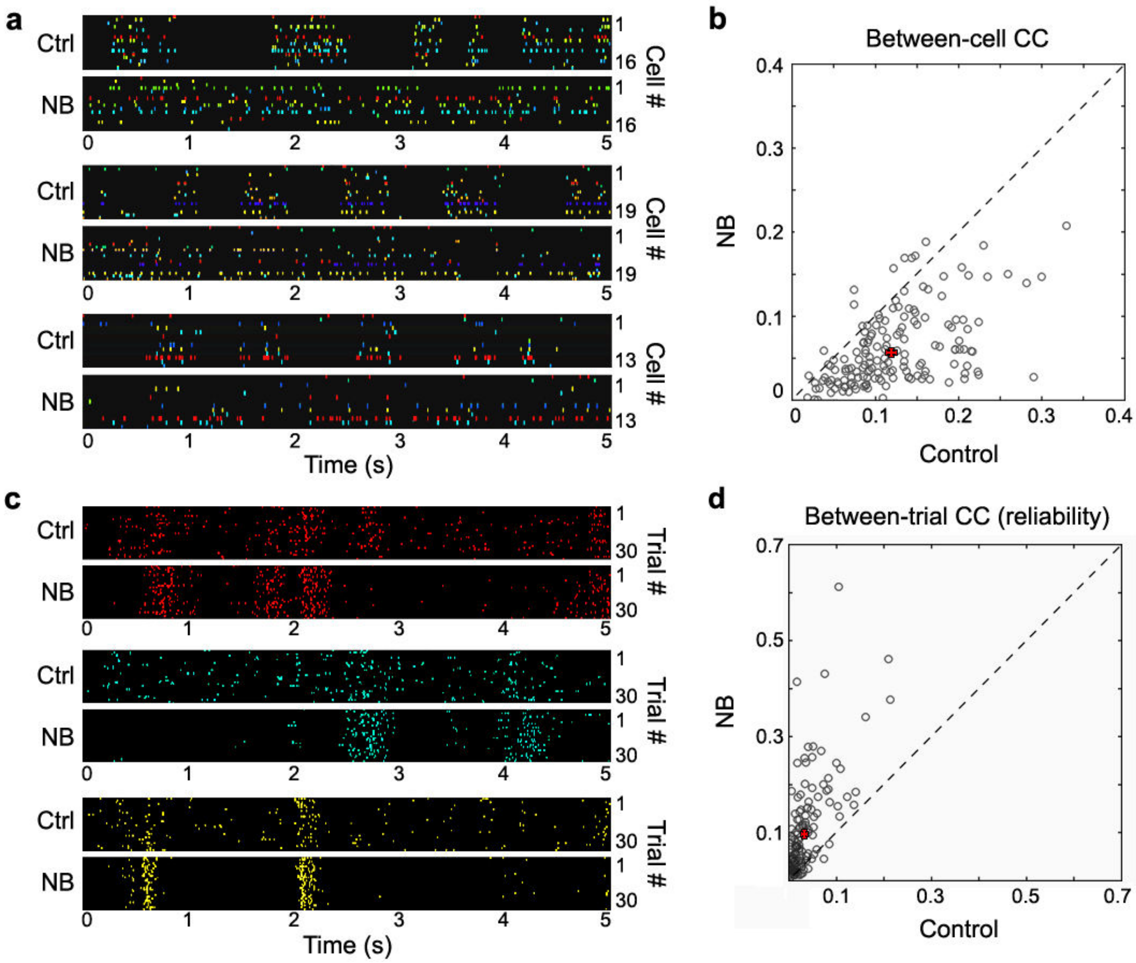
Supplementary Figures 1-7
Supplementary Table 1



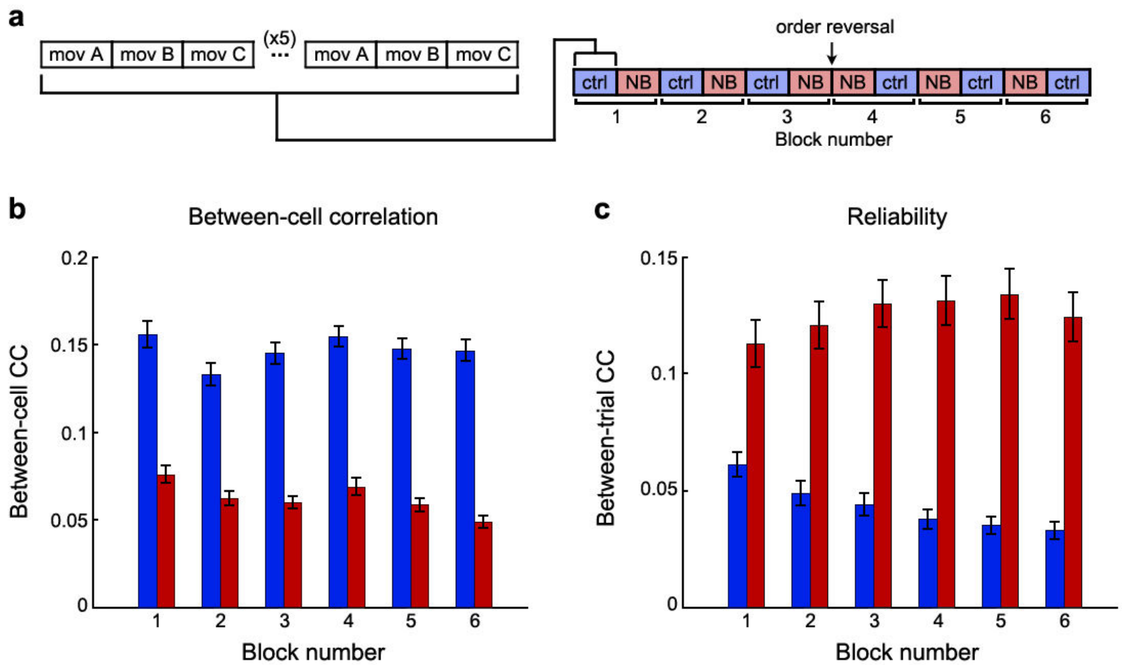
Supplementary Figure 1. Effect of NB stimulation on interhemispheric EEG. **(a)** Example EEG trace before and after NB stimulation at t = 0. **(b)** Amplitude spectra of EEG 1s before (blue) and 1s after (red) NB stimulation, averaged over 15 trials. Shaded area, ± s.e.m.

Supplementary Figure 2. Effect of NB stimulation on between-cell CC, between-trial CC, and firing rate in each cortical layer. **(a)** Between-cell CC before and after NB stimulation for neurons in layer 2/3 (green, *n* = 30 neurons), layer 4 (red, *n* = 40 neurons), layer 5 (blue, *n* = 77 neurons), and layer 6 (orange, *n* = 19 neurons), from 19 experiments. The effect was statistically significant for each layer ($P < 0.001$, Wilcoxon sign-rank test). **(b)** Between-trial CC (response reliability) before and after NB stimulation for neurons in each layer. The effect was statistically significant for each layer ($P < 0.001$, Wilcoxon sign-rank test). **(c)** Firing rates before and after NB stimulation for neurons in each layer. Nucleus basalis stimulation increased the firing rates in layers 4 (133%, P = 0.10, Wilcoxon signed-rank test), 5 (135%, $P < 10^{-6}$) and 6 (126%, P = 0.13), but decreased the rate in layer 2/3 (76%, P = 0.004). Error bars, ± s.e.m.

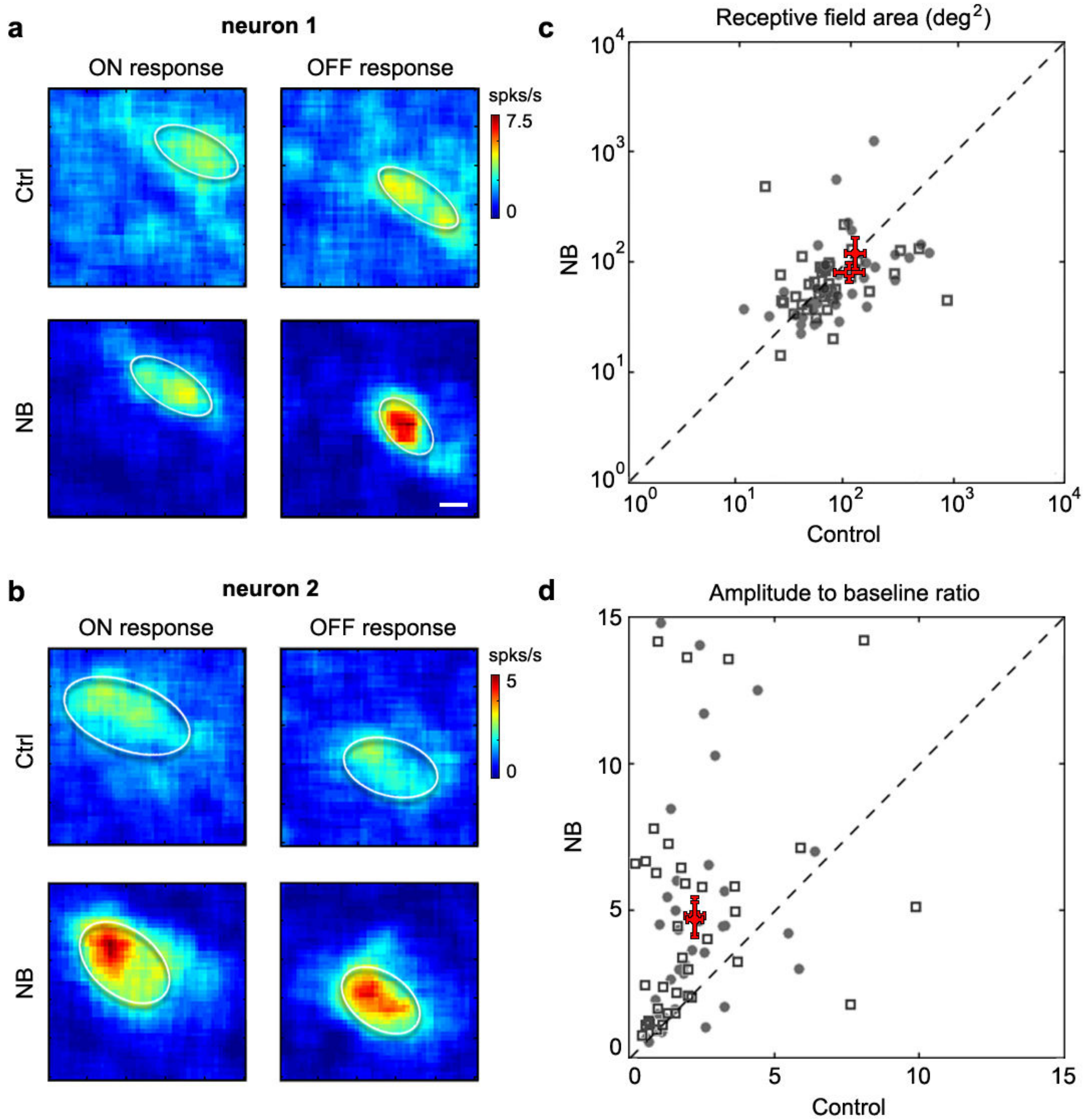




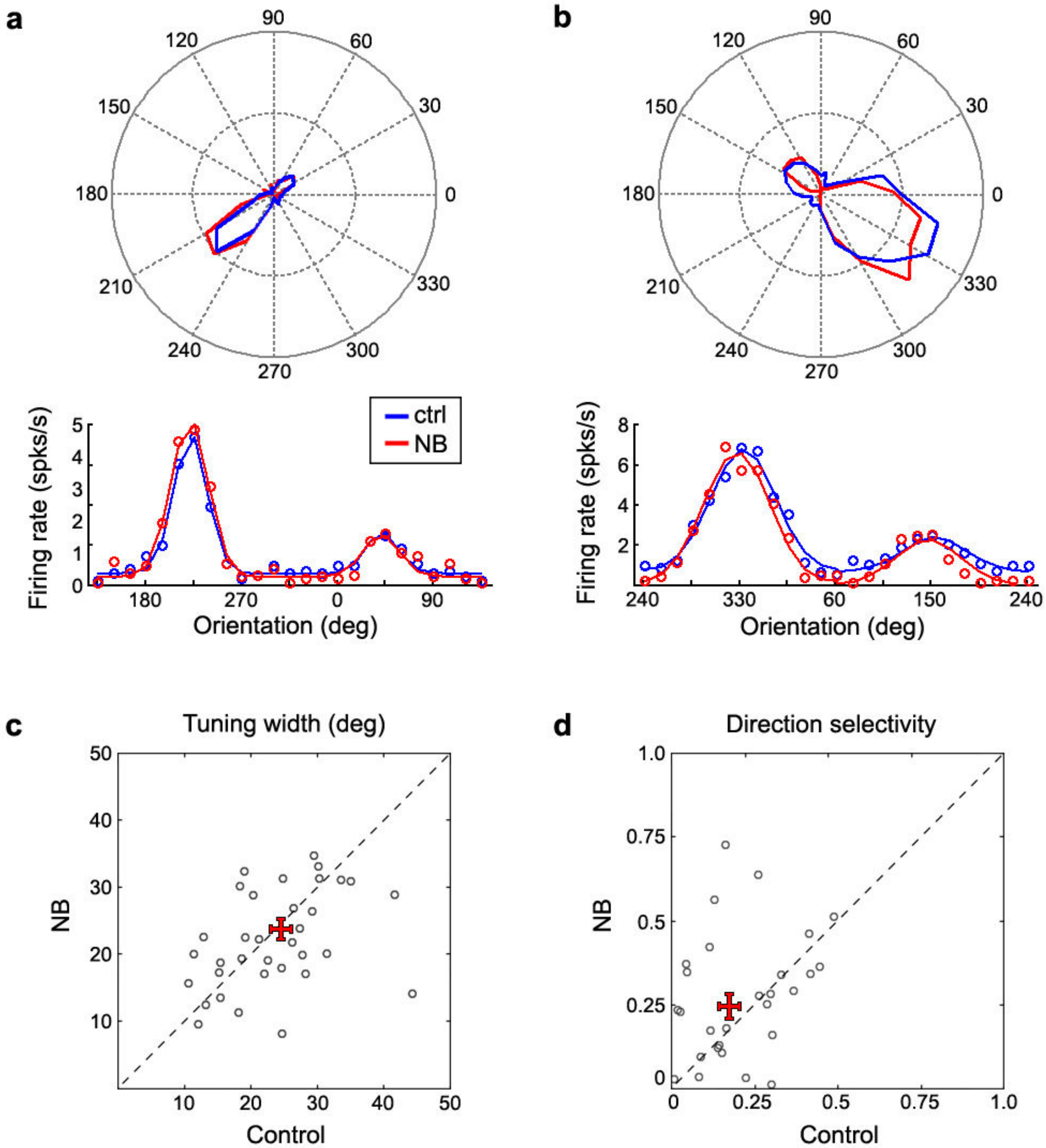
Supplementary Figure 3. Effects of NB stimulation on between-cell and between-trial CCs were not due to changes in firing rate. **(a)** Example experiments shown after the firing rates were equalized before and after NB stimulation by randomly removing spikes from the spike train with higher firing rate (same experiments as **Fig. 3a**). **(b)** Between-cell CC before and after NB stimulation after spike rate equalization. The NB-induced decrease in CC remained highly significant ($P < 10^{-22}$; n = 166 cells from 19 experiments). **(c)** Example neurons shown after firing rate equalization (same neurons as **Fig. 4a**). **(d)** Between-trial CC before and after NB stimulation after spike rate equalization. The NB-induced increase in CC remained highly significant ($P < 10^{-22}$; n = 166 cells from 19 experiments). Error bars, ± s.e.m.



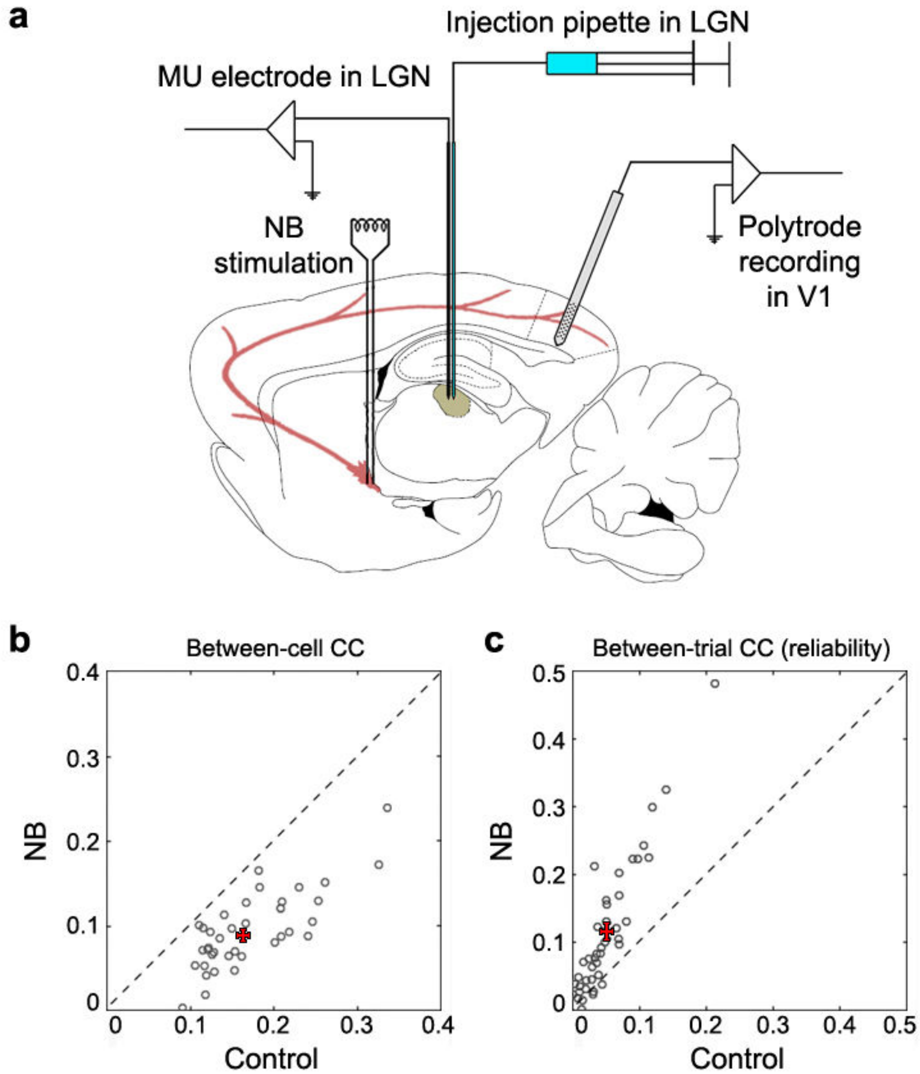
Supplementary Figure 4. Between-cell correlation and response reliability in different stimulus blocks under both control and NB conditions. **(a)** Schematic of movie presentation sequence. Each block consisted of 5 repeats of 3 movies. Control (ctrl, blue) and NB stimulation (NB, red) blocks were interleaved to reduce the confounding effect of cortical adaptation induced by repeated visual stimulation. **(b)** While the between-cell CC was similar across blocks for both control and NB conditions, CC (NB) was significantly lower than CC (control) in each of the 6 blocks. **(c)** Stimulation of NB significantly increased between-trial CC in each of the 6 blocks, with magnitudes much larger than the differences of CC across blocks. The slight reduction of between-trial CC over the control blocks may be caused by visual adaptation; the slight increase of CC over the NB blocks may result from enhanced ACh release induced by repeated NB stimulation. The opposite changes of reliability over time under the control and NB conditions further argue against the possibility that the observed effects are due to repeated presentation of the natural stimuli.



Supplementary Figure 5. Effect of NB stimulation on receptive fields of V1 neurons. **(a)** ON (left) and OFF (right) spatial receptive fields of a V1 neuron before (ctrl, top) and after (NB, bottom) NB stimulation. White ellipse, contour of Gaussian fit of the receptive field at one standard deviation along the major and minor axes. Scale bar, 5˚ of visual field. **(b)** ON and OFF receptive fields of a second neuron. **(c)** Summary of receptive field area before and after NB stimulation. Each symbol represents the receptive field of one cell (•, ON; □, OFF). Nucleus basalis stimulation did not significantly change the size of either ON or OFF receptive field (ON: P = 0.07, OFF: P = 0.41, n = 38 from 5 experiments). **(d)** Amplitude to baseline ratio before and after NB stimulation. Nucleus basalis stimulation significantly increased the amplitude to baseline ratio for both ON and OFF receptive fields (ON: $P < 10^{-4}$, OFF: $P < 10^{-4}$, n = 38 from 5 experiments). Error bars, ± s.e.m.



Supplementary Figure 6. Effect of NB stimulation on orientation tuning and direction selectivity. **(a)** Example V1 neuron showing orientation tuning and direction selectivity before (blue) and after (red) NB stimulation, plotted on polar (top) and Cartesian (bottom) coordinates. Cartesian plot shows raw data (circles) and Gaussian fit (line). **(b)** Orientation tuning and direction selectivity of a second V1 neuron. **(c)** Orientation tuning width before and after NB stimulation. Each symbol represents data from one cell. Nucleus basalis stimulation did not significantly change the tuning width (P = 0.78, n = 35 from 10 experiments). **(d)** Direction selectivity before and after NB stimulation. Nucleus basalis stimulation did not significantly change the direction selectivity (P = 0.20, n = 35 from 10 experiments). Error bars, ± s.e.m.



Supplementary Figure 7. Blockade of AChRs in the LGN did not diminish NB-induced decorrelation or increases in reliability in V1. **(a)** Schematic illustration of experimental setup. An injection pipette was bonded to a multi-unit recording electrode (used to map LGN multi-unit receptive field) and lowered into the LGN. NB stimulation and V1 polytrode recording are the same as in **Fig. 1a**. A mixture of atropine (100 μM) and mecamylamine (100 μM) was injected into the LGN before and during the recording in V1. **(b)** Summary of between-cell CC of V1 neurons before and after NB stimulation with AChR blockade in the LGN. Each circle represents the average CC between a single neuron and all other neurons in the same recording. Error bars, ± s.e.m. The NB-induced decrease in between-cell CC remained highly significant ($P < 10^{-7}$, n = 42 cells from 4 experiments). **(c)** Summary of between-trial CC of V1 neurons before and after NB stimulation with AChR blockade in the LGN. Each circle represents data from one neuron, averaged over CCs for all pairwise combinations of the 30 trials. Error bars, ± s.e.m. The NB-induced increase in between-trial CC remained highly significant ($P < 10^{-7}$, n = 42 cells from 4 experiments).

Supplementary Table 1. Effect of electrical stimulation on multiunit activity for experiments with and without significant EEG desynchronization

	ΔCC (between-channel)	ΔCC (between-trial)
EEG desyncronization present (mean ± SEM)	-0.16 ± 0.02	0.08 ± 0.01
EEG desyncronization absent (mean ± SEM)	-0.04 ± 0.03	0.02 ± 0.01

Experiments with significant EEG desynchronization (n = 19 experiments) showed a significant decrease in between-channel CC ($P < 10^{-7}$) and a significant increase in between-trial CC ($P < 10^{-8}$). Experiments without significant EEG desynchronization (n = 4 experiments) did not show a significant change in either between-channel or between-trial CC (P = 0.31 and P = 0.26, respectively).