Supporting Information

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SI Text

The artificial synaptic current (I_{syn}) was based on Sharp et al. (1) and was determined by the equation

$$I_{syn} = \bar{g}_{syn} \cdot S \cdot (V_{syn} - V_{post})$$
$$(1 - S_\infty)\tau_S \frac{dS}{dt} = (S_\infty - S),$$
$$S_\infty(V_{pre}) = \begin{Bmatrix} \tanh[(V_{pre} - V_{th})/V_{slope}] & \text{if} \quad V_{pre} > V_{th} \\ 0 & \text{otherwise} \end{Bmatrix},$$

where $\bar{g}_{syn}$ is the maximal synaptic conductance; S is the instantaneous synaptic activation; S_∞ is the steady-state synaptic activation; V_{syn} is the reversal potential of the synaptic current; V_{pre} and V_{post} are the presynaptic and postsynaptic potentials, respectively; τ_S is the time constant for synaptic decay; V_{th} is the synaptic threshold voltage; and V_{slope} is the synaptic slope voltage.

The artificial hyperpolarization-activated current was modeled after I_h in Buchholtz et al. (2):

$$I_h = \bar{g}_h R(V_h - V)$$
$$\frac{dR}{dt} = k_R(R_\infty - R),$$
$$R_\infty(V) = \frac{1}{1 + \exp[(V - V_{1/2})/s_R]}$$
$$k_R(V) = c_R\{1 + \exp[(V - V_{kR})/s_{kR}]\},$$

where $\bar{g}_h$ is the maximal g_h; R is the instantaneous activation; R_∞ is the steady-state activation; V_h is the g_h reversal potential; $V_{1/2}$ is the half-maximum activation; s_R is the step width; k_R is the relaxation rate; c_R is the rate constant; V_{kR} is the half-maximum potential for the rate; and s_{KR} is the step width for the rate. All parameter values were symmetrical for both GM neurons and are given in Table S1.

Spike Detection. Data were imported to Matlab by using Malcom Lidierth's SON library v2.31, and then analyzed by using our own scripts. Spikes were automatically identified from an analysis of the phase plot, dV/dt (y axis) vs. V (x axis). To decrease the impact of variability in the slow wave, V was high-pass filtered with a time constant of 30 ms, but dV/dt was left unchanged. Data with spikes yield distinct clockwise loops with few data points in the interior of the loops, whereas data without spikes yield points scattered throughout a roughly circular region. To detect spikes, we defined a point in the interior of the plot as a "central" point. The y coordinate of this point, $(dV/dt)_{central}$, was one-third of the maximum value obtained by dV/dt. The x coordinate of the central point, $V_{central}$, was one-third of the maximum value obtained by V. Putative spikes were identified as trajectories that began and ended with $V = V_{central}$, and looped clockwise around the interior point [specifically, they had $dV/dt > (dV/dt)_{central}$ before $V > V_{central}$]. The spike time was recorded as the time of peak voltage. To distinguish true spikes from the random fluctuations of a silent cell, a count was made of the number of trajectories that began and ended with high voltage ($V > V_{central}$) but low dV/dt [$dV/dt < (dV/dt)_{central}$]. If this number was >20% of the number of putative spikes, the data were classified as nonspiking, and all putative spikes were ignored. In practice, we found this to be nearly perfect at identifying spikes and distinguishing spiking from nonspiking data.

Burst Detection. Burst detection was performed by identifying times where the interspike interval was at least twice the mean (within-burst) interspike interval. Such long interspike intervals delineated the boundaries of candidate bursts. Because calculation of the mean (within-burst) interspike interval depends on the estimated burst times, we formed a preliminary burst analysis by looking for interspike intervals >4/3 the mean (whole trace) interspike interval, and then iteratively refined our burst detection based on the mean (within-burst) interspike interval obtained from the previous analysis. If any such candidate bursts were identified, we required the number of spikes in each burst be at least 2, and the standard deviation of the number of spikes per burst be <20% of the mean number of spikes per burst (to distinguish bursting regimes from Poisson spiking regimes). To aid in classification, we identified certain time intervals as active times for each cell. If the cell was bursting, the active time intervals were the same as the burst intervals, otherwise the active time intervals were chosen to be ¼ the average interspike interval and centered on each spike.

To determine whether a circuit was half-center, we calculated the total active time for each cell, t_{cell1} and t_{cell2}, and the overlap time (when both cells were active) for the circuit, $O_{network}$. We then compared $O_{network}$ to the overlap times that would be expected for uncorrelated circuits, O_{random}, and the minimum possible overlap time, O_{min}. From this we calculated the exclusion factor, $x_{network}$.

$$x_{network} = \frac{O_{random} - O_{network}}{O_{random} - O_{min}},$$
$$O_{min} = \begin{Bmatrix} T_{trial} - t_{cell1} - t_{cell2} & \text{if} \quad t_{cell1} + t_{cell2} > T_{trial} \\ 0 & \text{otherwise} \end{Bmatrix}$$

$$O_{\text{random}} = \begin{Bmatrix} \min(t_{\text{cell1}}, t_{\text{cell2}}) - \frac{1}{2}[T_{\text{trial}} - \max(t_{\text{cell1}}, t_{\text{cell2}})] & \text{if} \quad t_{\text{cell1}} + t_{\text{cell2}} > T_{\text{trial}} \\ \dfrac{\min(t_{\text{cell1}}, t_{\text{cell2}})^2}{2[T_{\text{trial}} - \max(t_{\text{cell1}}, t_{\text{cell2}})]} & \text{otherwise} \end{Bmatrix}.$$

Circuits with 2 active cells were categorized as half-center if $x_{\text{network}} \geq 0.1$ and were characterized as spiking otherwise.

1. Sharp AA, Skinner FK, Marder E (1996) Mechanisms of oscillation in dynamic clamp constructed two-cell half-center circuits. *J Neurophysiol* 76:867–883.
2. Buchholtz F, Golowasch J, Epstein IR, Marder E (1992) Mathematical model of an identified stomatogastric ganglion neuron. *J Neurophysiol* 67:332–340.

Table S1. Dynamic clamp parameter values

Parameter	Value	Units
g_{syn} and g_h	Varied from 10 to115	nS
V_{syn}	−80	mV
V_{slope}	10	mV
$V_{1/2}$	−50	mV
V_h	−10	mV
c_R	0.33	1/s
V_{kR}	−110	mV
s_{kR}	−13	mV
s_R	7	mV
τ_S	100	ms
V_{th}	−50	mV