Dynamical Bridge Between Song Degradation and Neural Plasticity

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Research Article

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Abstract

High dimensionality and complexity are the main difficulties of the study over network dynamics. Recently, Wilten Nicola proposed the mean field theory to research the bifurcations that the full networks display. Here, we use his approach on the birdsong neural network. Our previous work has shown that AFP could adjust the synapse conductance of nucleus RA and change RA's firing patterns, eventually leading to song degradation. To understand the dynamical principle behind this, we use a technique to reduce the RA network to a mean field model, in the form of a system of switching ordinary differential equations. Numerical results have shown that the mean field equations can qualitatively and quantitatively describe the behavior of nucleus RA. Based on the non-smooth bifurcation analysis of the mean field model, we determine that there is a subcritical-Andronov-Hopf bifurcation at a particular stimulation, which can explain the role of AFP during song degradation. The results indicate that we can see AFP's adjustment in RA synapse conductance as the adjustment of initial value in the bistable system. More precisely, during song degradation, the mean field system would transform to a stable node (corresponding to distorted songs) rather than a stable limit cycle (corresponding to normal songs).

Full Text

Figures

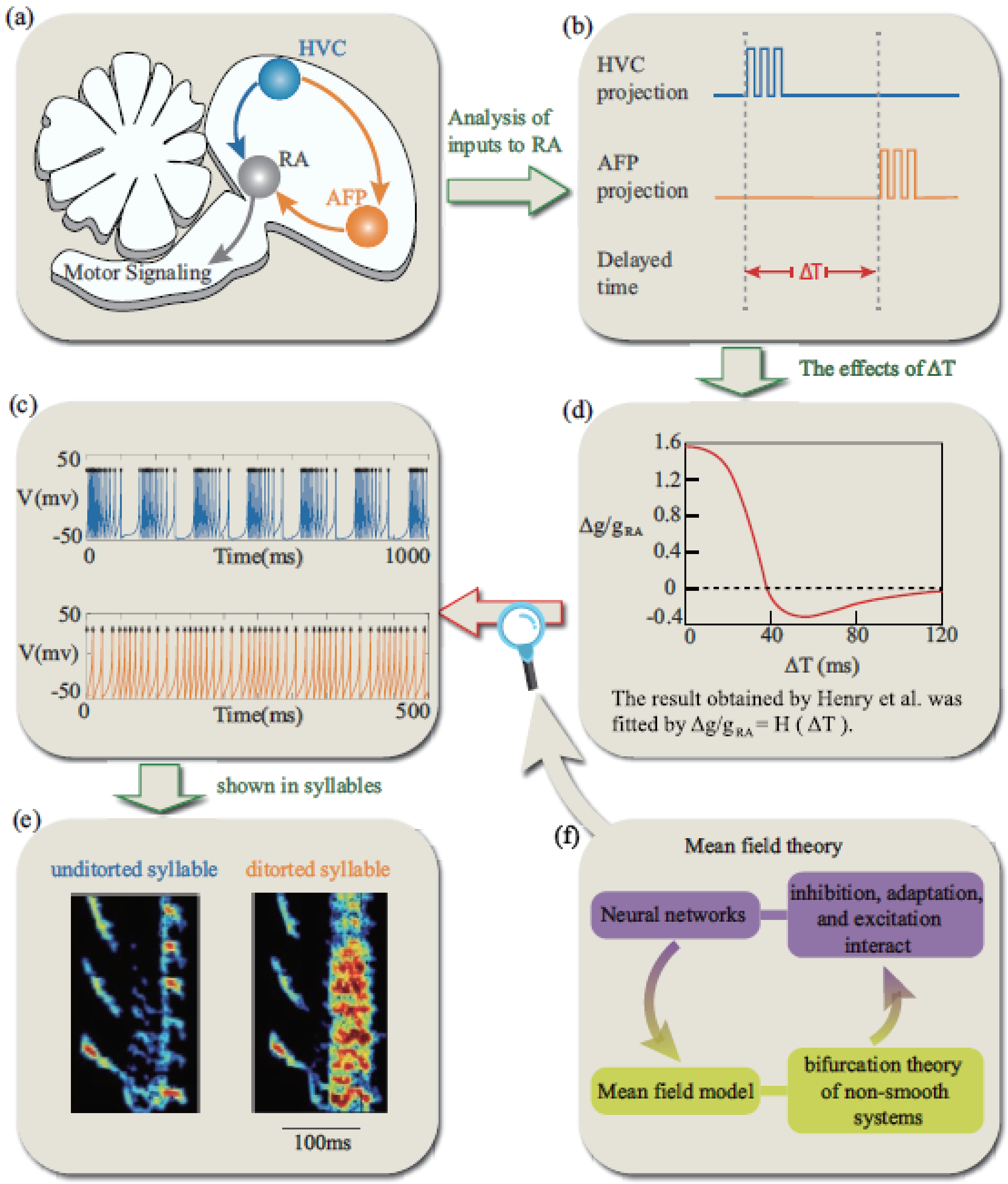

Figure 1

Schematic illustration of our research. (a) The physiological structure of the birdsong neural circuit. (b) Graph inter- pretation of the time difference, ΔT, between inputs to RA from AFP and HVC. (c) Our model shows two different firing patterns with different initial conditions within the same stimulus. (d) The effect of AFP on RA synapse conductance obtained by Henry. (e) Examples of syllables from Vikram Gadagkar. Reproduced with permission from references: [10], copyright 2016 AAAS. (f) Schematic of mean field theory.

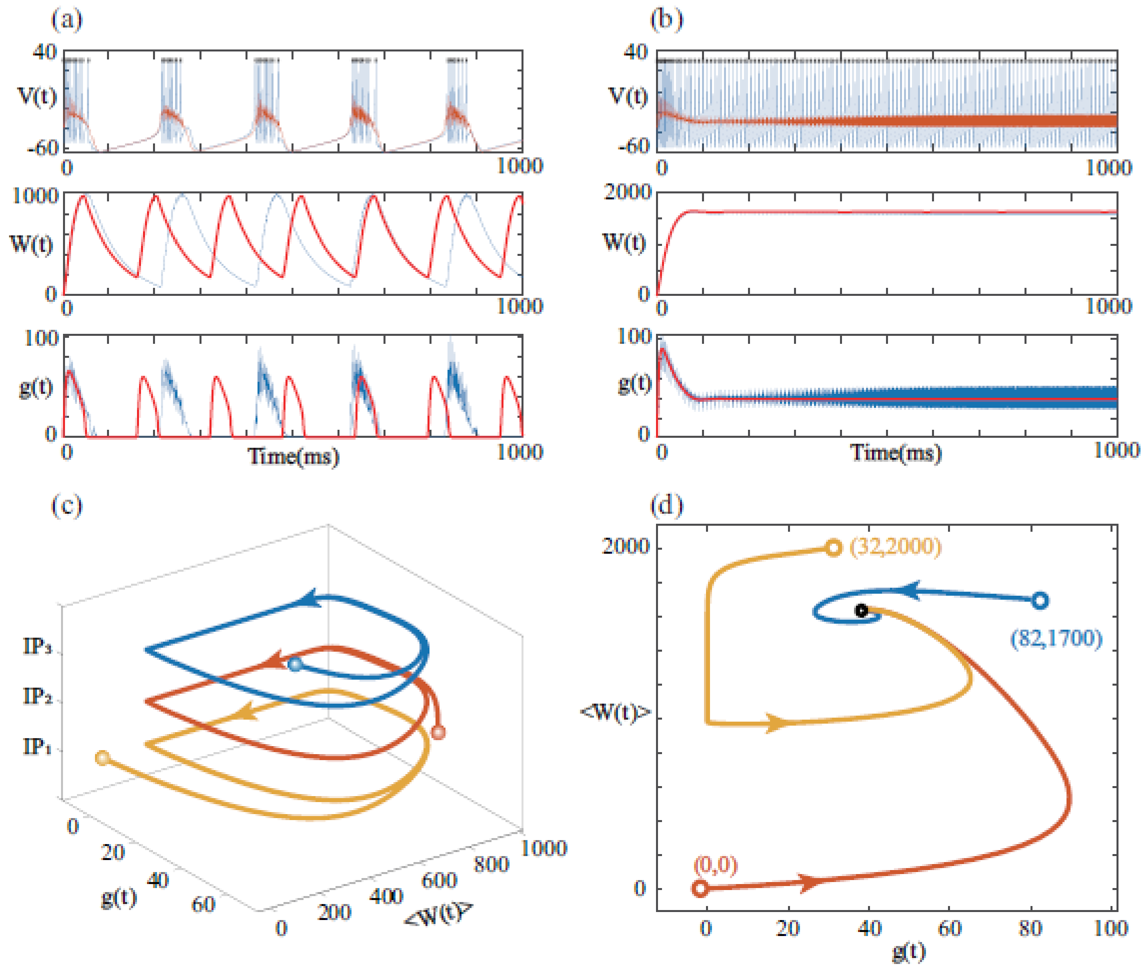

Figure 2

Simulation of biological network and mean field model. Diagrams (a)-(b) are behaviors from numerical simulation of original RA network and of the corresponding mean field model during bursting (Iapp = 1200 pA) and tonic firing (Iapp = 2000 pA), with orange lines referring to mean voltage of all neurons, blue lines to parameters of a random neuron, and red lines to variables in the mean field model. (c) Trajectories of bursting in the phase space (g(t), w(t)) of the mean field model with three different initial points, IP1 = (0, 0), IP2 = (50, 800), and IP3 = (20, 500). (d) Trajectories of tonic firing in the phase space, (g(t); <w(t)>), of the mean field model with three different initial points, IP1 = (0, 0), IP2 = (82, 1700), and IP3= (32, 2000).

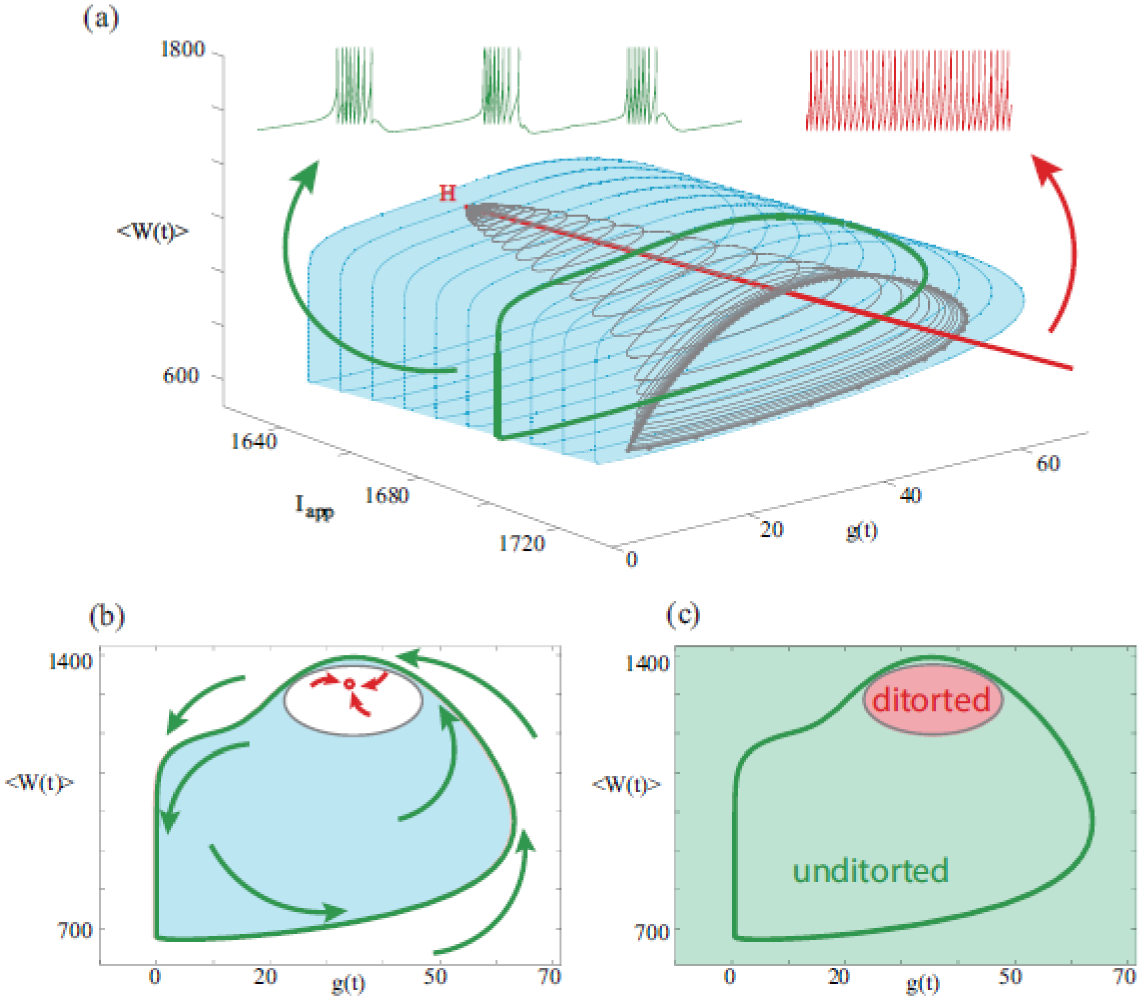

Figure 3

The subcritical Hopf bifurcation that occurs in the mean field model and cross-sections at IHopf = 1700 pA. (a) A subcritical Hopf bifurcation point appears at IHopf ≈ 1641 pA, which causes stable nodes (red line and referring to tonic firing) and unstable limit cycles (grey cycles). As stimulation increases, the unstable limit cycle grows and eventually touches the stable non-smooth limit cycle (blue surface), which corresponds to bursting. (b) The cross-section at Iapp = 1700 pA with a stable node (red point), an unstable limit cycle (grey cycle), and a stable non-smooth limit cycle (green cycle). (c) At Iapp = 1700 pA, mean field model with initial condition at the green region produces normal syllables and otherwise, it produces distorted syllables (corresponding to red region).

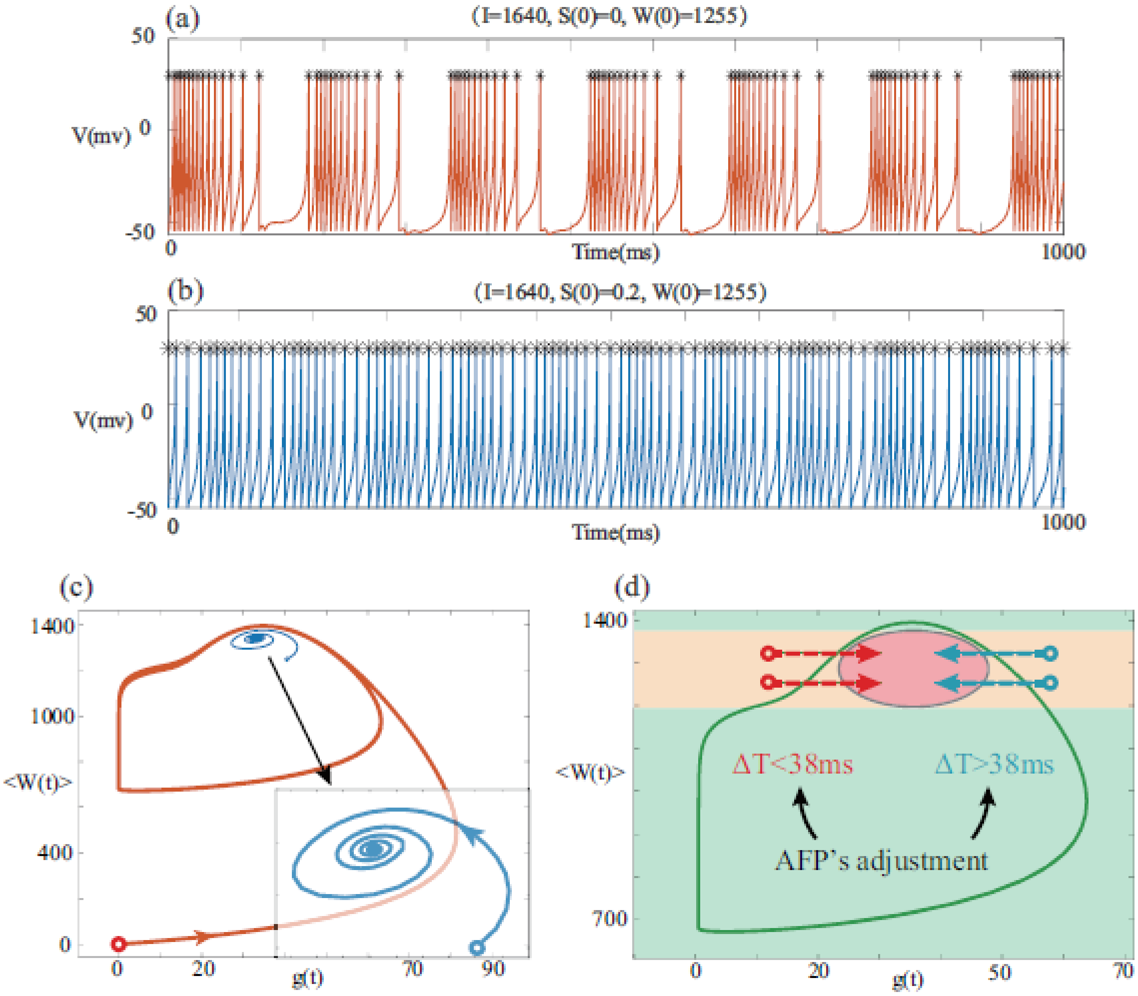

Figure 4

Numerical simulation of the original network and the mean field model at specific stimulation. (a) and (b) are two different firing patterns with the same stimulation and different initial conditions. (c) At the same stimulation, Iapp =1700 pA, both bursting and tonic firing appears from different initial points. (d) AFP can adjust RA network with an initial condition in the yellow region and change normal syllables into distorted ones.

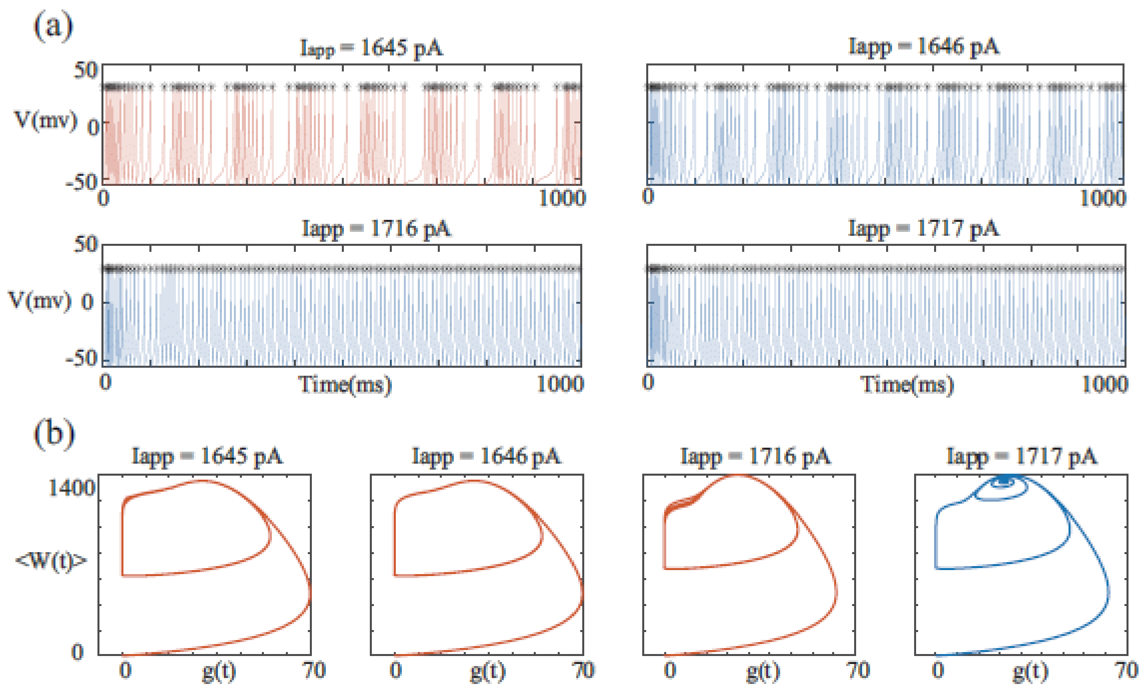

Figure 5

Numerical simulation of the original network and the phase space trajectory of the mean field model under different stimulations. (a) The network shows bursting in red (Iapp ≤1645 pA) and tonic firing in blue (Iapp >1645 pA). (b) The trajectory of the mean field model converges to the limit cycle (shown in red) when Iapp ≤1716 pA and to a stable node (shown in blue) when Iapp >1716 pA