Effects of Gap-Junction Coupling on the Activity Patterns of Noisy Neural Oscillators at Tonic-Bursting Bifurcations.

Horst Schneider, Svetlana Postnova, Karlheinz Voigt & Hans A. Braun

Institute of Physiology, Philipps-University Marburg, Deutschhausstr. 2, D-35037 Marburg, email: hschneid@staff.uni-marburg.de

Transitions from tonic firing to burst discharges are of high physiological and pathophysiological relevance in many neurons in the peripheral and central nervous system, e.g. for temperature encoding in skin cold receptor, for hormone release in hypothalamic neurosecretory cells and also for neuronal disorders like Parkinson's disease or epileptic seizures. In an intermediate range between tonic firing and regular bursts the neurons exhibit chaotic impulse pattern which is indicated by experimental data [1] and also can be seen in a Hodgkin-Huxley type neuronal model where impulses are generated by intrinsic subthreshold oscillations [2].

It can be expected that these particular dynamics of individual neurons will essentially be modified when they are connected to neuronal networks. Here we have examined how the dynamics change with nearest neighbor gap-junction coupling in a computer modeling study of a network of 10 * 10 identical neurons which are randomly set to different initial conditions and subjected to noise.

The simulations were run in tonic, bursting and chaotic regimes with different coupling. Tonically firing and bursting neurons synchronize already with low coupling strengths without significant changes of the impulse pattern. The more interesting phenomena can be observed in the chaotic regimes where it needs much stronger coupling strengths for the network to synchronize and where synchronized activity spreads from small neuronal clusters at variable, random positions. Moreover, chaotic dynamics in the neighborhood of the tonic firing range are eliminated. The neurons synchronize in a regular tonic-firing mode. Similar effects can be observed with chaotic activity close to bursting range where gap-junction coupling leads to synchronized chaotic bursts. However, in the chaotic regime it can also be observed that synchronization again disappears when the coupling strength is still more increased.

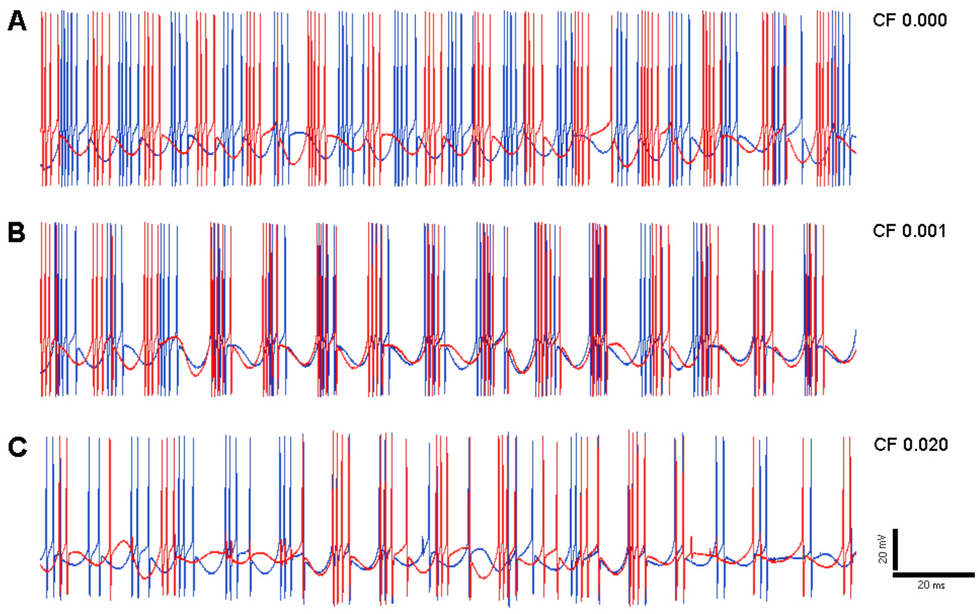

Figure: Firing of two neurons in a 10x10 neuronal network (neuron coordinates: red= 3/3, blue=7/7) at 12°C and different strength of gap-junction coupling. **A.** Without gap-junction coupling (CF=0.000) neurons show chaotic burst-like activity with random phase relations. **B.** At a small coupling strength (CF=0.001) the burst generation is synchronized. **C.** Stronger coupling (CF= 0.020) de-synchronizes the neuronal activity.

It should be important to further evaluate the specific conditions under which synchronized burst activity appears or will be destroyed in a neuronal network, because such transitions can be of particular relevance for physiological functions, e.g. hormone release, as well as for diverse neural disorders, like Parkinson's disease, and their treatments.

References:

[1] Braun HA, Voigt K, Huber MT (2003) Oscillations, Resonances and Noise: Basis of Flexible Neuronal Pattern Generation. Biosystems 71: 39-50.

[2] Braun HA, Dewald M, Voigt K, Huber M, Pei X and Moss F (1999b): Finding unstable periodic orbits in electroreceptors, cold receptors and hypothalamic neurons. Neurocomputing 26: 79-86.

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