Tuning the Entrainability of a Half-Center Oscillator

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1 Introduction

Biological oscillators display remarkable system properties. For instance, they can be robust to model uncertainty and variability whilst also displaying *entrainability*, that is, the ability to phase lock with the period of an external stimulus. An *entrainable* oscillator will easily synchronize or anti-synchronize to a rhythmic stimulus, while a non entrainable oscillator will maintain an endogenous rhythm regardless of its environment. Understanding the regulatory mechanisms of such properties might inspire design principles for engineering oscillatory systems, e.g. in rhythmic robotics. We consider the Half Centre Oscillator model, the archetype of oscillatory circuits in cellular neuroscience, and we investigate a novel regulatory mechanism to modulate the entrainability of the oscillator.

2 Half-Center Oscillator Model

The Half-Center Oscillator (HCO) is an elementary neural circuit consisting of two neurons reciprocally coupled by inhibitory synapses. This elementary model is the archetype example of Central Pattern Generator (CPG) whose existence was hypothesized by T. G. Brown [3] more than a century ago. Since then, large sets of data have supported its existence in various animals circuits, where they control a variety of rhythmic tasks such as locomotion and breathing. The translation of this paradigm in robotics goes back to the seminal paper by A. J. Ijspeert [4] and the references therein.

The antiphase rhythm of the HCO rests on a simple mechanism: the end of a burst in one neuron causes the other neuron to produce a *rebound* burst, the end of which elicits the next rebound burst in the other neuron. Despite the simplicity of this mechanism, detailed understanding of the HCO has generated papers for more than a century. There is general agreement that the rebound property of the individual neurons is crucial to the robustness of the circuit rhythm.

The paper [2] by J. Dethier et al. (2014) establishes a key functional difference between two distinct currents that are known to contribute to the rebound mechanism: the transient Calcium current $I_{Ca,T}$ provides a source of slow, positive feedback (*slow regenerativity*) whereas the hyperpolarization-activated current I_H does not. The authors proceed to show that this particular form of feedback at the cellular level is essential for the robustness and modulation properties at the circuit level.

In the present paper, we model the HCO using the neuromorphic design approach proposed in [1] for a more intuitive tuning. The model consists of parallel sources of feedback at different timescales and is therefore ideal to study the effects of slow regenerativity.

3 Cellular tuning of network entrainability

We investigate the balance between $I_{Ca,T}$ and I_H as a mechanism to tune the entrainability of the oscillator. With only $I_{Ca,T}$, the oscillator is endogenous and only entrains to external stimuli in a narrow frequency range. With only I_H, the oscillator is very entrainable but also very fragile. The circuit rhythm requires a precise (and rather strong) tuning of the synaptic coupling. The rhythm of such an exogenous burster cannot be adjusted at a cellular level. It requires a fine tuning of the entire circuit.

We observe that the proper balancing of $I_{Ca,T}$ and I_H is a robust and appealing regulatory mechanism of entrainability. This mechanism provides a novel example of a circuit property that can be neuromodulated at the cellular level, enabling fine regulation in a variable and uncertain environment. We will discuss the potential of tuning the entrainability of an oscillator in the context of neuromorphic circuit design for robot locomotion.

References

[1] L. Ribar and R. Sepulchre, "Neuromodulation of neuromorphic circuits", *IEEE TCAS-I*, 2019

[2] J. Dethier, G. Drion, A. Franci and R. Sepulchre, "A positive feedback at the cellular level promotes robustness and modulation at the circuit level", *JNP*, 2014

[3] T. G. Brown, "The intrinsic factors in the act of progression in the mammal", *Proc. R. Soc. Lond. B*, 1911

[4] A. J. Ijspeert, "Central pattern generators for locomotion control in animals and robots: A review", *J. Neural Netw.*, 2008

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