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The Role Of The Receptive Field Structure In Neuronal Compressive Sensing Signal Processing

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finally, only IID2 s occurs with depolarization of V_{GABA}. We hypothesize that in the experiments V_{GABA} was depolarized because of depressed action of potassium-chloride cotransporters in the conditions with high extracellular potassium concentration. We have also found the synaptic depression to be a crucial factor, which provides ceasing of each of the discharges and determines their duration. Overall, our study reveals the mechanisms of pathological synchronization with the primary role of excitatory GABA receptors in the interneuronal network.

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Neural activity in distinct navigation modes of flying pigeons

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In spatial navigation, there are certain tasks of choosing a route or correcting a route depending on external conditions. It is necessary to respond to changes in the visual environment, to compare the expected and observed landscape. Quick reaction is required in case of unexpected obstacles on the pathway. Perception is detailed as the target is approached. Orientation awareness is accompanied by various types of neuronal activities. It can be observed in brain cells associated with navigation (including place cells, grid cells, head-direction cells) [1], and in combinations of rhythms of neural ensembles [2]. Contributions of different band oscillations during route selection can be independent [3]. Observed brain activities are different in tasks with the specified position of the visual cue or with underspecified movement goal [4].

This work proposes a model to identify the characteristics of brain activity of flying pigeons with different modes of space perception. Pigeons fly home based on familiar landmarks and landscape features [5], solar, stellar and magnetic cues, polarized light patterns [6], and other references to geographical location. Pigeons have color and ultraviolet vision, their eyes distinguish the 75 frames per second, field of view is 340 degrees. Comparison of EEG responses to visual landmarks in flying pigeons was described [7].

The work considers pigeon flight on known route in three modes: 1. Stationary flight at an altitude of 100-300 meters, speed of 60 km/h. For flight in a given direction it is necessary to take into account the influence of wind (drift angle). 2.Response to danger or sudden changes. Pigeons are more sensitive to radial motion when there is an acceleration as opposed to a constant velocity [8]. 3. Descent and landing. Birds begin to fly in circles at an altitude of 30-50 meters.

In the computational model, it is assumed that each mode is accompanied by a characteristic set of rhythms of neural ensembles (for quiet flight, for alarm and for approaching to visible goal). Representation of brain activity as sets of rhythms depends on the type of mode. In model, recognition of textures and borders in the mode "stationary flight" is additionally encoded by the phase of rhythms with lower frequency. Interactions between cortical rhythms may generate a third frequency [9]. Route reference points are additionally encoded by the amplitude of rhythms in all modes. QGIS (http://www.qgis.org) allows to integrate data received from various sources simultaneously. In the work, GPS track of flights and landscape maps are performed in QGIS (similarly, QGIS was applied in [6]). In addition, the program allows to combine results of EEG data processing with the spatial characteristics of pigeon flight. In the spatial representation of the model takes into account the distances between the reference points on the ground.

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The Role of the Receptive Field Structure in Neuronal Compressive Sensing Signal Processing

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The receptive field structure ubiquitous in the visual system is believed to play a crucial role in encoding stimulus characteristics, such as contrast and spectral composition. However, receptive field architecture may also result in unforeseen difficulties in processing particular classes of images. We explore the potential functional benefits and shortcomings of localization and center-surround paradigms in the context of an integrate-and-fire neuronal network model. Utilizing the sparsity of natural scenes, we derive a compressive-sensing based theoretical framework for network input reconstructions based on neuronal firing rate dynamics [1, 2]. This formalism underlines a potential mechanism for efficiently transmitting sparse stimulus information, and further suggests sensory pathways may have evolved to take advantage of the sparsity of visual stimuli [3, 4]. Using this methodology, we investigate how the accuracy of image encoding depends on the network architecture.

We demonstrate that the receptive field structure does indeed facilitate marked improvements in natural stimulus encoding at the price of yielding erroneous information about specific classes of stimuli. Relative to uniformly random sampling, we show that localized random sampling yields robust improvements in image reconstructions, which are most pronounced for natural stimuli containing a relatively large spread of dominant low frequency components. This suggests a novel direction for compressive sensing theory and sampling methodology in engineered devices. However, for images with specific gray-scale patterning, such as the Hermann grid depicted in Fig. 1, we show that localization in sampling produces systematic errors in image encoding that may underlie several optical illusions. We expect that these connections between input characteristics, network topology, and neuronal dynamics will give new insights into the structure-function relationship of the visual system.

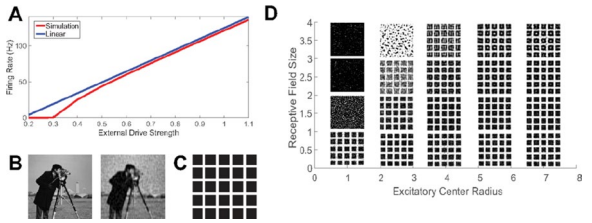

Figure 1. A. The network-averaged firing rate dependence on the external-drive strength scaling, computed using model simulation and theoretical linear input-output mapping. **B.** Original image (left) and CS reconstruction (right) using localized random sampling of the network dynamics. **C.** Hermann grid illusion. **D.** Reconstructions of (C) for various choices of receptive field size scaling and excitatory center region radius

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FuNS with E/I balance: critical dynamics maximize stability of neural networks

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The mammalian brain naturally balances excitation and inhibition. This results in complex dynamics vital for important cognitive functions such as the formation of new memories. Excitatory/inhibitory (E/I) balance has been shown to result in scale-free distributions of population behavior known as neuronal avalanches, a hallmark of self-organized criticality in the brain. Recently, we have shown using models well-rooted in physics that new memories are stored only when the system dynamics reside near a critical point and are characterized by enhanced stability of spiking activity which we refer to as functional network stability (FuNS) [1]. Here, we expand on this work through direct modeling of neuronal networks where E/I balance is tightly controlled. Proximity to criticality at E/I balance is verified via calculation of neuronal avalanches as well as through calculating functional connectivity correlation between neurons for increasing separation distance between them. Introducing a region of increased coupling, such as the synaptic potentiation involved in learning, increases FuNS in networks exhibiting E/I balance significantly over networks whose dynamics arise primarily through excitatory or inhibitory inputs. Our results indicate that networks with balanced excitation and inhibition have an increased ability to store memories through increased functional network stability, a phenomenon due in part to critical dynamics in neural systems.

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Neural oscillations modulate the network dynamics around E-I balance in memory consolidation

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Rhythmic activities of different frequency bands have been observed universally in the brain and are thought to play important roles in various cognitive processes [1]. However, the fundamental mechanism of how these neural oscillations contribute to brain activities is still an open question. Recently, via both computational simulations and in vivo experiments, we found that oscillations are essential for memory consolidation as they mediate network functional stability. We have shown computationally, that various network properties such as firing rate, synchrony, mean phase coherence are enhanced in the presence of external oscillations around Excitatory-Inhibitory (E-I) balance, where E-I ratio is calculated based on the excitatory and inhibitory synaptic strength and neuronal firing frequency. We have investigated this effect for both type 1 (integrator) neurons as well as type 2 (resonator) cells. The networks composed of resonator neurons are more sensitive to the oscillatory drive than the networks composed of integrator neurons, however both show significant changes in firing patterns. We show that global oscillations causally organize firing patterns between heterogeneous networks composed of dense neuronal clusters that are loosely connected with each other, facilitating communication and information transfer between spatially distributed brain regions. Most importantly, near Excitatory-Inhibitory (E-I) balance, oscillations increase both functional connectivity between neurons and coherence between spikes and local field potential (LFP), as well as enhance network functional stability, thus leading to faster changes in network structural connectivity patterns thought to underlie learning and memory consolidation. These in silico observations are supported by our experimental data [2]. In summary, our results show that neural oscillations together with network state near E/I balance coordinate the network dynamics and contribute to memory consolidation.

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Cellular and network properties of interneuron networks dictate variable clustering patterns in both strictly inhibitory and E-I neural networks

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The diverse population of interneurons in the hippocampus is pivotal to the formation of oscillatory electrical activity that contributes to memory processing [1], while in the cortex such interneurons and rhythms are implicated in potential mechanisms underlying selective attention [2]. Computational research has shown that these rhythms can be generated in purely inhibitory networks or networks with both excitatory and inhibitory neurons (E-I networks). However, the dynamics and mechanisms generating them depend on properties of the inhibitory network.