Hippocampal Interneurons and Theta Oscillations

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Hippocampal theta oscillations provide a temporal time frame in which assemblies of pyramidal cells encode the representations of space and episodic memory. The occurrence of network oscillations, the selection of pyramidal cells firing together and forming a specific representation and the exact timing of the pyramidal cell firing are not determined by sensory input alone, but are also shaped by the internal organisation of the local hippocampal network. GABAergic interneurons are key components in regulating the activity of pyramidal cells and the entire network.

Currently we recognise at least 18 distinct neuronal sources of GABA in the CA1 area; 13 types of interneuron innervate specific domains of pyramidal cells, approximately 4 types of interneuron innervate mostly other interneurons in addition to the septo-hippocampal GABAergic pathway. The interneurons innervating pyramidal cell include: (1) axo-axonic cell, (2) parvalbumin-expressing basket cell, (3,4) vesicular glutamate transporter positive or negative CCK expressing basket cells, (5) bistratified cell, (6) Schaffer collateral associated cell, (7) O-bistratified cell, (8) O-LM cell, (9) back-projection cell, (10) trilaminar cell, (11) neurogliaform cell, (12) lacunosum-moleculare perforant path associated cell, (13) lacunosum-molecular-radiatum perforant path associated cell. Mainly or exclusively interneuron innervating GABAergic cells include: (14) septo-hippocampal cell and the (15-17) interneuron specific cells I-III. Undoubtedly, ongoing studies will modify this list, but the number of distinct sources of GABA is unlikely to become smaller. The number of brain and other hippocampal areas innervated by CA1 GABAergic cells will also significantly increase.

The spike timing of different types of identified hippocampal interneurons in anaesthetized rats exhibit distinct temporal firing patterns during theta oscillations. Consequently, the different excitatory inputs, the cellular summation of electrical events and the output of pyramidal cells are under the control of temporally distinct GABAergic inputs. We conclude that the exact timing of firing of interneurons, together with the spatial restriction of GABA release sites to certain domains of the pyramidal cells, regulate and promote the formation of cell assemblies and representations in the hippocampus.

Discussion points:

- What are the functional consequences of the different firing patterns of distinct interneuron classes during theta oscillations?
- Does the accurately timed GABA release to different domains of pyramidal cells have differential effects on the “average” silent pyramidal cells and the active place cells?
- Would the implementation of distinct interneuron firing patterns improve computational models of theta oscillations?