Spatial selectivity and theta phase precession in CA1 interneurons

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The traditional hypothesis has been that most of the information processing of neural networks is carried out by excitatory cells, which send out their axons to downstream structures. In the cortex, including in the hippocampus, inhibitory neurons are present in a lower proportion than excitatory cells and have local processes. These characteristics have led to the idea that interneurons merely modulate the global activity of the network through nonspecific suppression of excitability. However, based on their exquisite diversity and complex functional characteristics, there is now growing evidence that interneurons might play a much more refined role than initially thought.

In the CA1 region of the rat hippocampus, pyramidal cells discharge selectively when the animal is in specific locations in its environment, called the place fields of the cells. Furthermore, the firing exhibits a precise relationship with the ongoing rhythmic activity of the network: as the rat traverses a place field, spikes display progressively earlier phases relative to the theta oscillation (phase precession). Thus both rate coding and temporal coding coexist in this region, at least in the excitatory population.

The goal of this study has been to investigate the spatial selectivity and theta phase dynamics of interneurons in CA1. We recorded the activity of both excitatory and inhibitory cells using the multi-tetrode recording technique, as well as the continuous local field potential from the stratum radiatum for the theta rhythm. Rats ran repeatedly back and forth for food reward on a linear circular track. Spatial selectivity was quantified by the mutual information between the firing rate of the neurons and the location of the animal. Using this measure, inhibitory interneurons showed robust and stable spatial selectivity. As previously reported in the literature, we observed strong phase locking of interneuron firing to the theta rhythm. Furthermore, on sections of the track, the range of theta phases shifted progressively to earlier parts of the theta cycle as the rat advanced, so that a negative correlation between phase and position could be demonstrated in single interneurons. These spatially-restricted segments of phase precession coincided with local peaks in the firing rate.

These results indicate that spatial selectivity and phase precession in CA1 are not properties restricted to pyramidal cells. Rather, they may be a more general expression of a common interaction between the different inputs impinging on both excitatory and inhibitory cells in CA1 and the intrinsic characteristics of those cells. This hypothesis is discussed in the framework of a simple model of phase precession. We conclude that the role of interneurons may extend beyond a global damping of the network by participating in a finely-tuned local processing with the pyramidal cells.

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