Chapter 2
Brain Maps for Space

May-Britt Moser

Abstract The brain controls spatial navigation in mammals by activating functionally specialized cell types in the medial temporal lobe. Key components of the spatial mapping system are place cells and grid cells. It has been known for some time that place cells are located in the hippocampus and are active only when the animal is entering a specific location in the environment. Here, we present our research results relating to grid cells. We found that grid cells are located upstream of the hippocampus, in the medial entorhinal cortex, and are activated whenever an animal enters locations that are distributed in a spatially periodic pattern across the environment. Moreover, we discovered that the grid cell network is intrinsically organized as grid cells clustered in distinct and independent grid maps with distinct scales, orientations and asymmetries, as well as distinct grid patterns of temporal organization.

Keywords Place cells · Grid cells · Grid maps · Spatial navigation

2.1 Main Contribution

The brain controls spatial navigation in mammals by activating functionally specialized cell types in the medial temporal lobe. A key component of the spatial mapping system is the place cell,located in the hippocampus. These cells—discovered by O'Keefe and Dostrovsky in 1971—are active only when the animal is entering a specific location in the environment. I will describe the discovery of another component of the mammalian spatial mapping system—the grid cell—which we found upstream of the hippocampus, in the medial entorhinal cortex, in 2005. Grid cells are activated

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M.-B. Moser (✉)
Norwegian University of Science and Technology, Kavli Institute for Systems Neuroscience and Centre for Neural Computation, Trondheim, Norway
e-mail: may-britt.moser@ntnu.no

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whenever an animal enters locations that are distributed in a spatially periodic pattern across the environment. The repeating unit of the grid pattern much is an equilateral triangle. Grid cells are co-localized with head direction cells and border cells, which contain information about the direction in which the animal is moving and the boundaries of the environment. Despite the discovery of several elements of the mammalian spatial map, the interaction between the components is poorly understood. We addressed this question first by using optogenetics together with electrophysiological recordings of cells in the entorhinal cortex. Hippocampal neurons were infected with an adeno-associated virus carrying genes for a peptide tag that can be visualized by fluorescent antibodies as well as the light-sensitive cation channel channelrhodopsin-2 (ChR2). The virus was engineered to enable retrograde transport through axons of cells with projections into the hippocampus. Infected entorhinal cells were detected by local flashes of light. Channel rhodopsin-expressing cells responded with a short and constant latency to the light. All cell types in the entorhinal cortex were found to respond to the light, suggesting that place signals may be generated in the hippocampus by convergence of signals from all these entorhinal cell types. In addition to discussing the transformation of entorhinal to hippocampal spatial signals, I will devote a part of my talk to asking how the grid-cell network is intrinsically organized. To address this question, we used multi-channel recording from a much larger number of cells than recorded ever before in individual animals. Grid cells were found to cluster into a small number of modules with distinct grid scales, grid orientations and grid asymmetries, as well as distinct patterns of temporal organization. The different modules responded independently to changes in the geometry of the environment.

The existence of distinct and independent modules or grid maps makes entorhinal maps different from the many other sensory cortices where functions tend to be more graded and continuous.

This is in agreement with the suggestion that the grid map is a product of self-organizing network dynamics rather than specificity in the input. Because the crystal-like structure of the grid pattern is generated within the brain, not depending on specific sensory inputs, we are confronted with a unique situation in which we, by trying to understand how the grid pattern is formed, may obtain insights into how patterns are formed in the mammalian cortex.

2.2 Editors' Comments

Professor May-Britt Moser is the Founding Director of Centre for Neural Computation and co-Director of the Kavlil Institute for Systems Neuroscience. PhD in neurophysiology, University of Oslo 1995.

She is interested in the neural basis of spatial location and spatial specifically and cognition more generally. Her work, conducted with Edvard Moser as a long-term collaborator, includes the discovery of grid cells in the entorhinal cortex, as well as several additional space-representing cell types in the same circuit.

Her group is beginning to unravel the functional organization of the grid-cell circuit as well as its contribution to memory formation in the hippocampus.

May-Britt Moser was a co-Founder of the Centre for the Biology of Memory, a Research Council-funded Centre of Excellence from 2003 to 2012, and has taken on the Directorship of the Centre for Neural Computation, with a life time from 2013 to 2022.

May-Britt Moser Won the Nobel Prize in Physiology or Medicine 2014. She shares the Nobel Prize with Edvard Moser and John O'Keefe.

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